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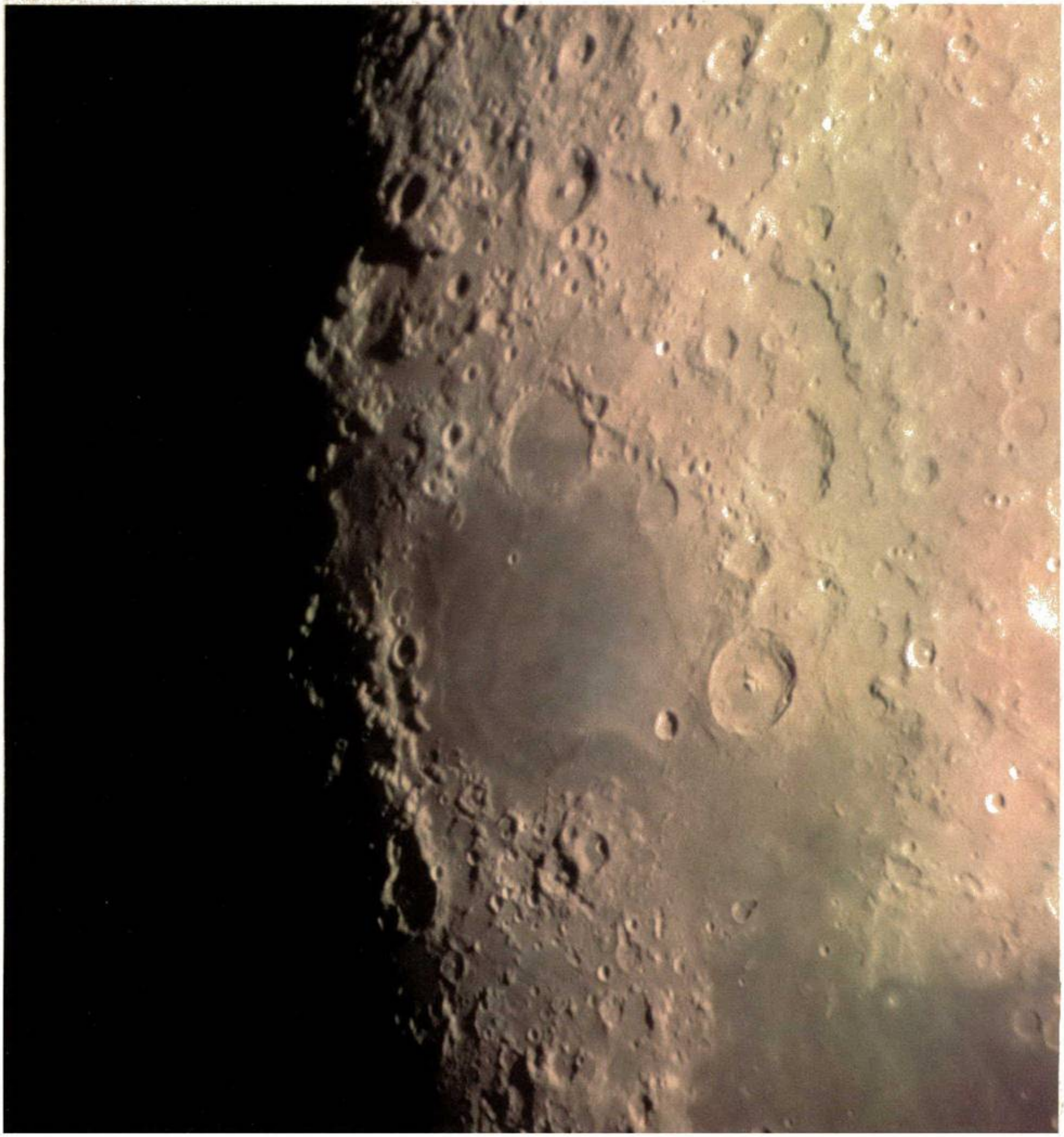

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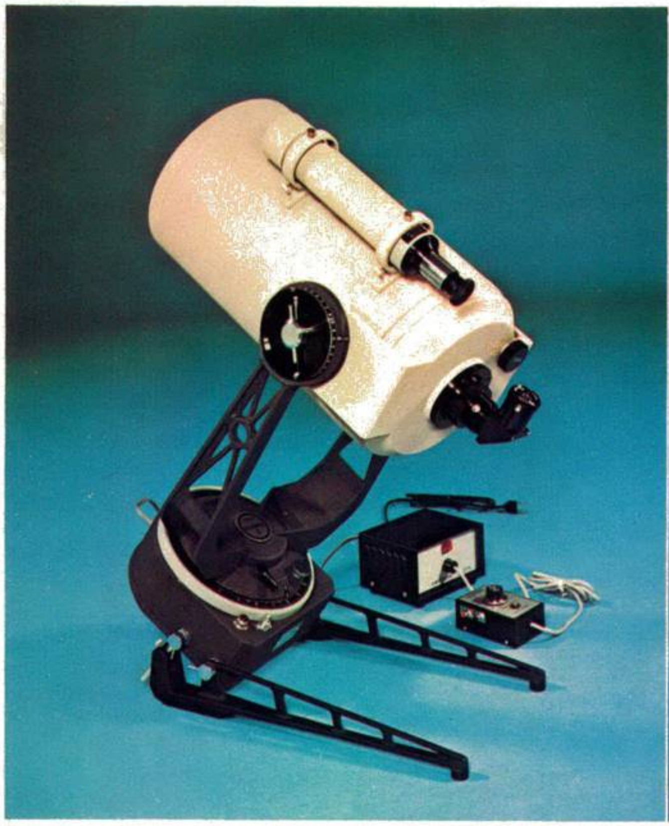

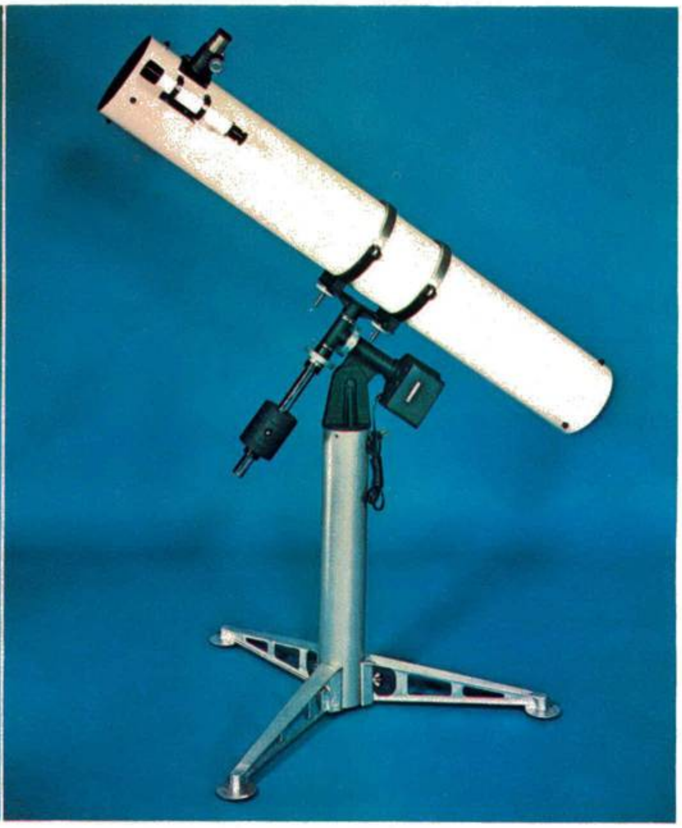

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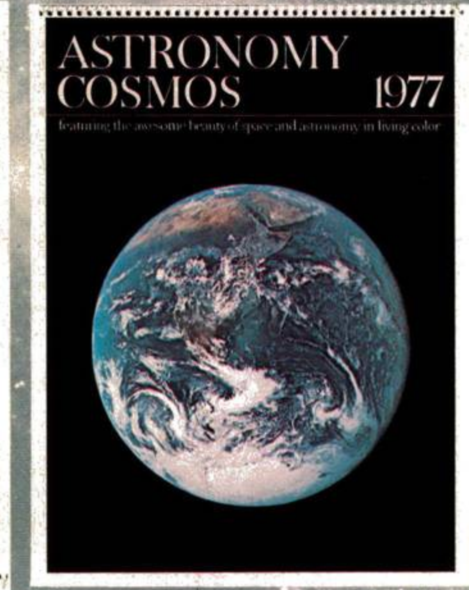
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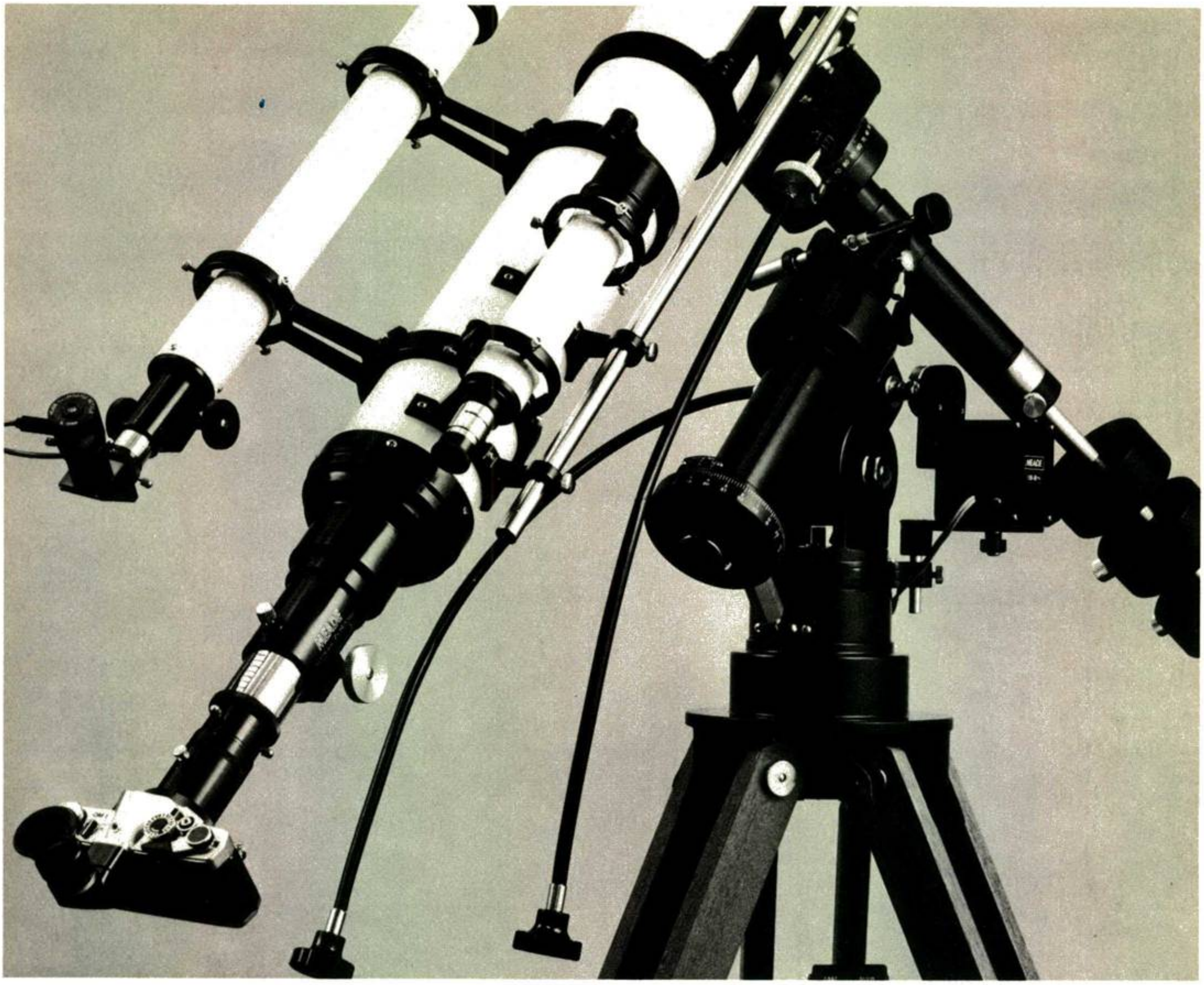

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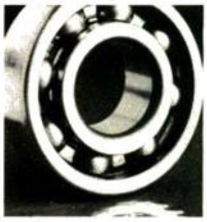

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May 1977 Vol. 5, No. 5

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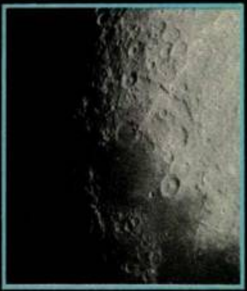

Cover

As endless in its fascination for modern man as it was for the ancients, the moon — our nearest neighbor in space — presents its timeless, unchanging vistas year after year. Our cover photograph shows the region of Mare Nectaris; prominent along the mare's edges are the craters Fracastorius and Theophilus, while near the terminator the Pyrenees Mountains catch the last rays of the setting sun. This month, ASTRONOMY presents two discussions of cosmological subjects: the mysterious origins of life and the equally cryptic end of the universe. Where are we going and where have we been? There are no definite answers, but we speculate on the possibilities. ASTRONOMY also continues its series on astronomers in space and building your own six inch reflector, as well as providing suggestions for astrophotos to take on vacation. Photograph by Andrew W. Steinbrecher.

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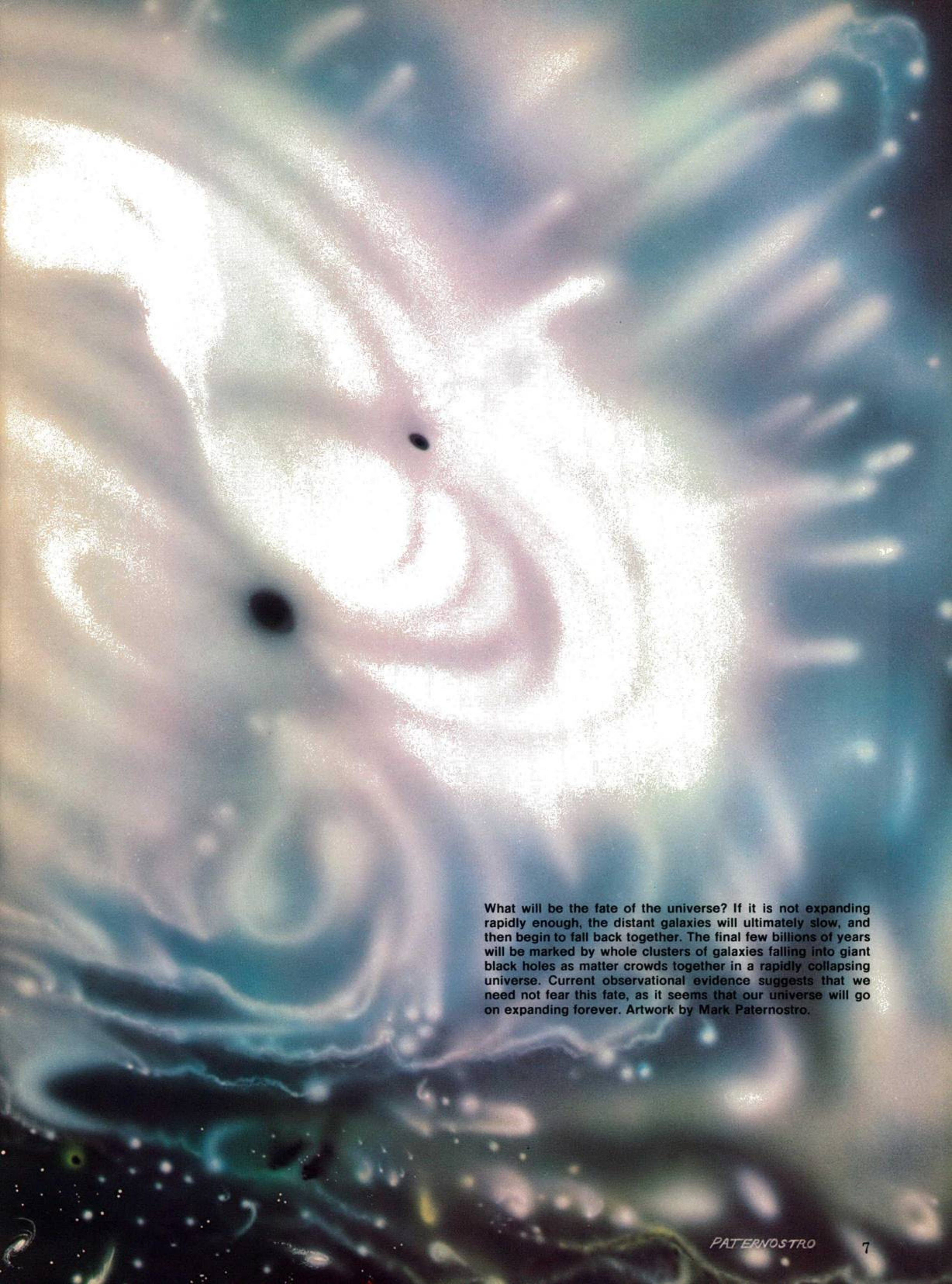
THE END OF TIME

by
Barry Parker



What will be the fate of the universe? If it is not expanding rapidly enough, the distant galaxies will ultimately slow, and then begin to fall back together. The final few billions of years will be marked by whole clusters of galaxies falling into giant black holes as matter crowds together in a rapidly collapsing universe. Current observational evidence suggests that we need not fear this fate, as it seems that our universe will go on expanding forever. Artwork by Mark Paternostro.

Looking out through space on a starry night, you can hardly fail to feel a sense of awe. What does it mean? Does space and time stretch on forever? With the question of immortality being uppermost in man's mind, we inevitably ask, "Will it ever come to an end?" We know, of course, that we cannot live forever, but somehow we would like to think that our succeeding generations will go on forever.

It is difficult for most of us to accept the idea that someday there may not be an Earth. In fact, as we shall see, there may not even be a universe. Perhaps it is fortunate that it is so difficult for us to visualize how long a few billion years is; it will be this long before Earth or the universe will be gone! There's a good chance that long before this, all life on Earth will have ceased as a result of man's destructive devices. At any rate, there's no doubt that our succeeding generations will not go on forever — but will all life come to an end? This depends on what eventually happens to the universe.

Let's begin by looking at the future of Earth. What's in store for it? All life here depends on the stars in a galaxy we call the Milky Way.

Astronomers are now confident they understand many of the things that go on in a star. Like people, stars have a life cycle. They are born, live for a few billion (million in some cases) years, and then die. Their deaths can be quite different. Some die slowly (small stars become white dwarfs over billions of years); others explode spectacularly and then end as neutron stars, while others become the mysterious black holes. The fate of a specific star depends on its mass at birth; this also determines the length of its life. A star has only so much fuel, and when it is used up, it dies.

Near the end of its life, a star expands and becomes more luminous. In about three to five billion years our sun will be larger and almost twice as bright as it is now. As it grows larger, surface temperatures here on Earth will rise, and it will be shrouded in a heavy overcast — much as Venus is now. The sun's radiation will become trapped beneath this dense cloud layer, causing a runaway greenhouse effect as it is reflected back and forth between it and Earth's surface. Temperatures and pressures will skyrocket. Gradually Earth's surface will become a seething sea of molten rock and lava. All life will be gone.

Fortunately, this will not happen for a few billion years, so we will have sufficient time to prepare. By then we will easily be able to travel to Mars and other outer planets. And, strange as it seems, as Earth dies a lingering death, Mars will become more comfortable and balmy. As the sun expands, its ecosphere (life zone) will move outward; Mars will be in the center of it — much as we are today. This may help delay the end of civilization, but it won't stop it. Eventually our sun will become a tiny white dwarf. After a few billion more years, it will end as a dead sphere of cosmic ash.

By then man may have developed his technology to where he can travel to distant stars — but even the stars cannot last. The life of our galaxy is also limited, because it is composed of stars and, as we know, all stars eventually die. Some explode, throwing off gigantic clouds of gas into space that eventually develop into new stars. This revitalizes the galaxy, but as this goes on, other stars die. Small stars, white dwarfs and neutron stars all eventually become cosmic ash.

Don't forget black holes — they don't help things either! In fact, some scientists now believe that it may be black holes that "do us in". As they swallow nearby matter, they grow larger and larger. More continue to coalesce. Eventually the entire core of our galaxy may be a gigantic black hole. Then, finally, it too will be gone.

This brings us to the universe itself. Does it have a similar fate in store? What will eventually happen to it? The survival of life depends inevitably on the answer to this question. If the universe survives, our galaxy may die. But new ones will form and stars with planets will undoubtedly form in them — possibly planets on which life can develop.

A universe that goes on forever with new galaxies being continually formed has, of course, been postulated in the *steady state* theory. In the last few years, however, the steady state has run into an ever-increasing number of problems. Conflict between the theory and observations is so great that few astronomers believe it is still a viable theory. Fred Hoyle has modified it, bringing it in line with observation, but even this has not helped. Of course, there is always the possibility that as new discoveries are made it will be revived.

Most astronomers now believe that the *big bang* theory (or at least some slight variation of it) is our best description of the universe. This theory assumes that the universe began about 20 billion years ago as an explosive expansion of an extremely dense (possibly infinitely dense) primordial nucleus, and it has been expanding ever since. Edwin Hubble has shown that this expansion is linear. In other words, if you compare the velocity of two galaxies — one twice as far away from us as the other — the more distant one will be traveling twice as fast as the closer one. It might seem from this that we are at some chosen position of the universe with all galaxies receding from us. But this is not the case. All galaxies recede from one another. The way to think of it is to assume the space between the galaxies is increasing or stretching. A two-dimensional analogy

Galaxies age and die, just as the individual stars within them age and die. Although gas from the supernovae may be reprocessed through several generations of stars, it will eventually end up in a cool, low mass star with a lifetime measured in hundreds of billions of years. A galaxy such as this one (NGC-2841) is still actively forming new stars in its spiral arm — you can see whole clouds of them as tiny knots in the arms. Hale Observatories photograph.

Right: The distant galaxies are moving away from us as we are moving away from them. Similarly, all objects in the universe are moving away from each other as space-time expands. Artwork by Mark Paternostro. Above: The expansion becomes apparent only over the giant distances to remote clusters of galaxies. An example is the cluster containing NGC-545 through NGC-547 (and radio source 3C-40), as shown in this 48 inch Schmidt photograph. Hale Observatories photograph, courtesy of Dr. Paul Hodge.

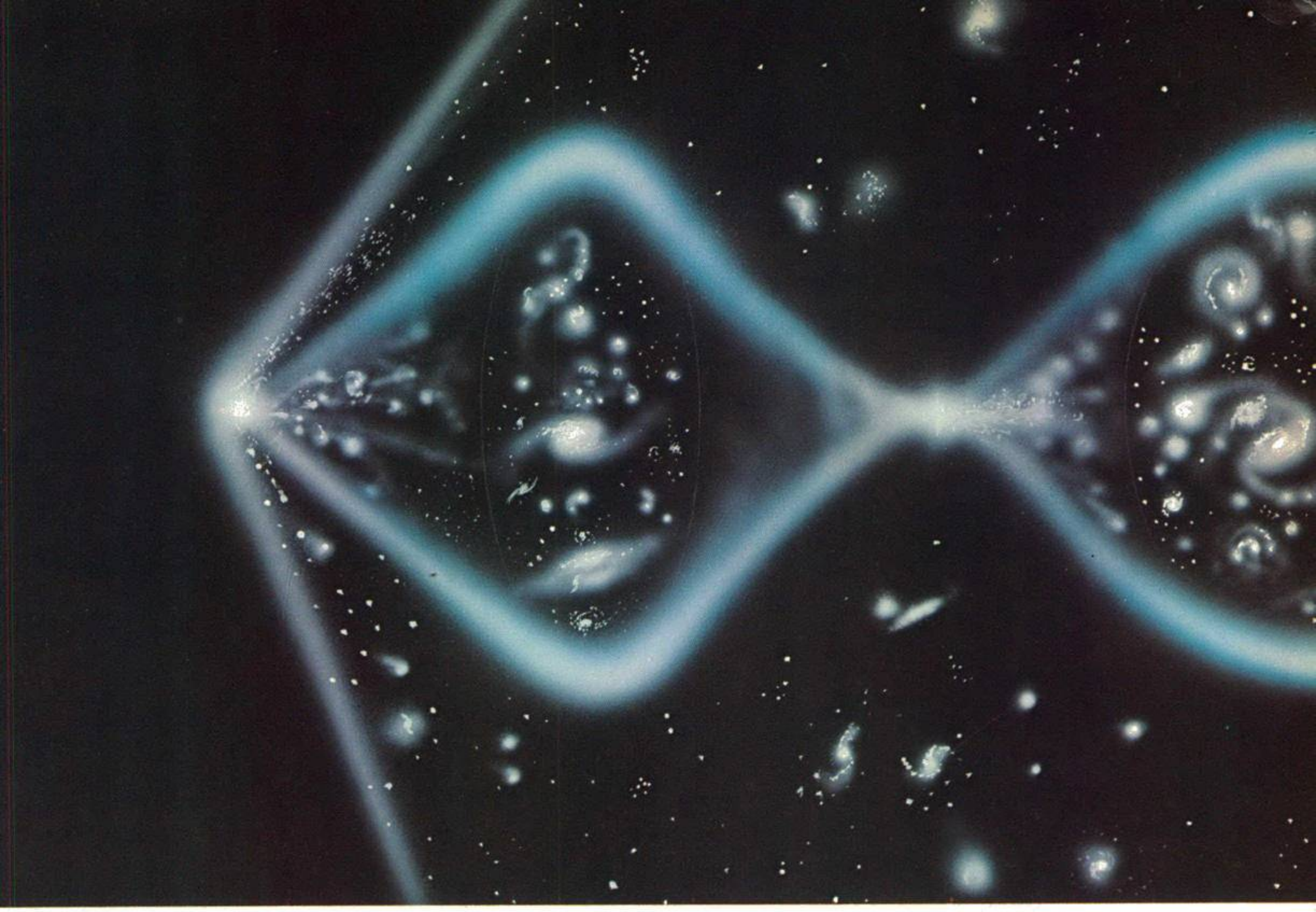
that is frequently used is a balloon with small circles (representing galaxies) pasted on it. As the balloons are blown up, the distance between the circles increases.

With our model established, let's go back to the question of what will eventually happen to it. If the universe is expanding now, there are obviously two alternatives: It can continue expanding forever, or it can eventually stop. The reasoning behind these alternatives will become clearer if we compare the explosion of the universe to a small scale explosion here on Earth. The debris that expands outward in this case eventually stops. But you have to be careful in making a comparison; each piece of debris receives a certain amount of energy from the explosion. As it moves outward, it loses some of this energy to air resistance. Most of it, however, is lost to the pull of gravity.

Consider one of the pieces of debris in detail — for example, one that goes directly upward. Like a ball thrown upward, it goes only so far; then it stops, reverses its velocity and begins to fall back toward Earth. It accelerates in such a way that when it reaches the ground it has the same velocity as it had there when it was ejected upward (disregarding air friction, of course). There is a possibility, however, that this piece of debris would not fall. If, for example, it had a speed greater than the escape velocity of Earth (approximately 25,000 m.p.h. or 40,000 k.p.h.), it would completely overcome our planet's gravitational field and move off into space, never to return.

Let's look at the explosion of the universe with this example in mind. Remembering that all galaxies are expanding away from us — but that we are not at a privileged position in the universe (they are expanding away from every point in the same way) — we ask, "How do we go about making a direct comparison?" The best way is to examine part of the universe at a time. Since it is completely homogeneous on a large scale (one of the basic assumptions of cosmology), each part or region will act in the same way. In other words, whatever happens to one sphere of galaxies will happen to all similar spheres in the universe.

We'll begin by selecting a large sphere of galaxies around us. But what about the gravitational force on this sphere as a result of the galaxies around it? Because of their homogeneity, they will cancel



one another. In other words, a push or pull on one side of the sphere will be exactly balanced by an equal one on the other side — resulting in no forces. This means that we can study our sphere and then extrapolate our results to the entire universe.

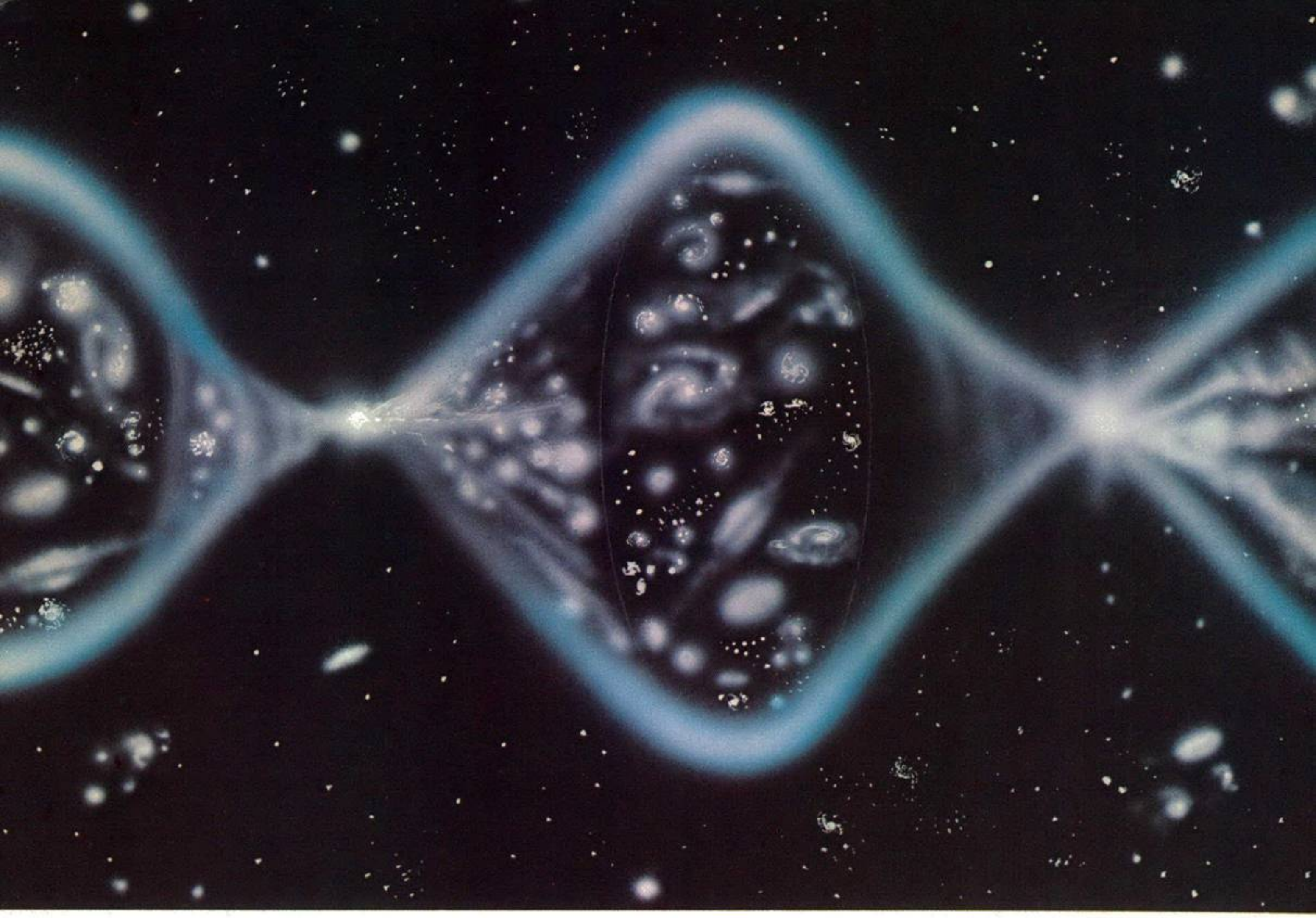
The galaxies in our sphere are all expanding away from one another, but there is a net gravitational force acting on the ones near the edge, pulling them back toward the center of the sphere. This will cause them to slow down or decelerate. If the deceleration is sufficient they will eventually stop, and then begin to move inward toward the center. Whether or not they actually will stop depends on the total amount of matter in the sphere. This matter determines the escape velocity from the sphere just as Earth's mass determines the escape velocity from it. If the average density is *greater than* a certain ciritical amount (about 6×10^{-30} grams per cubic centimeter), the galaxies will eventually stop and begin to collapse back toward the center. The universe is said to be *closed* if this is the case. On the other hand, if the average density is *less than* the critical amount, the galaxies will continue to separate indefinitely. The universe will expand forever (it will be *open*).

So, we see that there are two possible fates for the universe: It can expand forever, or it can eventually stop and collapse inward on itself. The central question of cosmology is: Which of these two cases will occur?

Is the universe going to collapse again and again and again — endlessly oscillating? Or has it exploded just once, to continue expanding forever? Here, space is shown on a vertical axis, while time runs horizontally left to right. As time goes on, an oscillating universe expands in space and then collapses to expand again. A big bang universe expands indefinitely, becoming less and less dense as it ages.

Before we attempt to answer this, let's look at an interesting aspect of the collapse. Will the entire universe eventually become a gigantic black hole? It's certainly likely that during collapse, the numerous black holes already in the universe will grow extensively. As the average density increases they will draw more and more matter in. Many will collide and coalesce. And, indeed, the universe will finally be a black hole. But it will not suddenly become one; it won't even collapse unless it is already a black hole. This may sound a little strange, but it can easily be shown by a simple calculation.

"But how could the universe be a black hole?" you may ask. "It's practically a vacuum." It turns out that when we deal with something as large as the universe, the usual ideas of what a black hole should look like just don't apply. The universe is



so large that it can be a black hole even though it has an exceedingly low density of matter. If we compared a collapsing star's density of matter just as it becomes a black hole (that is, just passing through its gravitational radius) to a similar — but much larger — black hole in the collapsing core of a galaxy, we'd find that the density of the larger black hole was much less. And as we continue to go to even larger black holes, the density continues to decrease. By the time we get to a black hole as big as the universe, the density is exceedingly low.

Returning to the question of whether or not the universe will collapse, let's consider how we can determine the answer. There are several tests that can be made, but unfortunately the difficulties involved in carrying out the required measurements are extreme, and there is even doubt in some cases whether the test itself is a good one. We will discuss only two of the most important of these tests.

We have already mentioned one. As we have seen, the only force acting on expanding galaxies is gravity, and the magnitude of this force depends on the amount of matter in the universe. Accurate measure of the average density will, therefore, give us the answer to our problem. Unfortunately, it is far from easy to obtain this. Galaxies and other visible matter are no problem; the problem is with the matter we cannot see. Hydrogen gas, small stars, dead stars, black holes and radiation are all examples of this type of matter, and it's quite possible there is much more matter tied up in these forms than there is in galaxies. (Some astronomers have estimated that there may be 10 times as much.) But even with this, it seems there is not enough to cause it to stop expanding. It would still need 10 times as much again.

It's possible that even this extra factor may often be there. J.P. Osteriker and P.J.E. Peebles, both of Princeton University, and A. Yahil of Tel Aviv University have shown that current estimates of the masses of galaxies may be too small by a factor of 10. They point out that most galaxies appear to be embedded in an enormous sphere of very faint stars. If the mass of the extensive halo is included in the total density, it would be just sufficient to close the universe.

Others disagree, feeling strongly that on the basis of other evidence there is little chance that the universe really has sufficient mass to close it. Strong feelings, weak feelings or whatever, we simply don't know for certain how much mass there is. Edward R. Harrison of the National Radio Astronomy Observatory has stressed that difficulties lie in trying to estimate contributions due to such

things as dead galaxies and primordial black holes.

But what do other tests tell us? One of the best is a test of deceleration of the outermost galaxies. As we look outward at these galaxies, we are actually looking back in time. We see the most distant ones as they were almost eight billion years ago. Closer ones can be seen as they were less than one billion years ago. By comparing the outermost galaxies to those nearby, we can tell how much they are slowing down. If they are decelerating at a rate greater than a certain critical rate, then the universe will eventually collapse; if not, it will expand forever. [A deceleration parameter q is selected as a measure; if q is greater than q critical (q critical =1/2), the universe is open; if it's less, it's closed.]

Now, how do we determine q? In principle, it's found from a Hubble plot — a graph of velocity (or redshift) versus distances for the galaxies. But the points arising from the most distant galaxies are most interesting, and by far the hardest to measure. Determination of the distance to these objects is particularly difficult. We must first measure the apparent brightnesses, and then determine from it the absolute brightness. Fortunately, nature has provided a way for us to do this. The largest galaxies of galactic clusters are essentially all of the same size and shape. This means we can study them in nearby clusters and determine their absolute brightnesses relatively easily; the information can then be used to study them in distant clusters. Once we know their absolute magnitudes, we can combine them with their apparent magnitudes and determine their distances.

The procedure is more difficult than it sounds. First, the apparent brightness of extremely faint galaxies is very difficult to determine accurately. And even if we could get a good estimate of it, our troubles would not be over. We are seeing these galaxies as they were seven or eight billion years ago. What do they look like today? How have they changed during this time? Stars grow old and die; some explode, eventually giving birth to new stars. The changes are undoubtedly significant, but we don't know exactly what they are — we can only guess. Large black holes in their core, for example, could significantly alter their appearance. And large galaxies have a tendency to swallow smaller nearby galaxies, also altering them.

There are, of course, other tests, but they do not bring us closer to an answer. If we accept things at face value, the present evidence seems to favor an open, forever expanding universe. But this is far from conclusive. Things may change significantly in the next few years as new evidence accumulates. (Only 10 years ago, evidence seemed to favor a closed universe. At that time, Allan Sandage of Hale Observatories estimated the cycle to be approximately 80 billion years.)

On the other hand, James Gunn of Hale and Beatrice Tinsley of Yale University argued that the universe is not only not decelerating, but that it may be accelerating. Is this possible? Let's look at our analogy — the ball thrown upward. We know it decelerates until it gets to a certain height; then it turns around and accelerates toward Earth. If it was projected hard enough it might escape Earth's gravity, but it would still decelerate as it traveled upward.

Comparing this to the Gunn-Tinsley hypothesis, it would be like having the ball accelerating upward and escaping forever. But we know this is impossible, unless there's something we don't know about the universe. Most of our theories are based on Einstein's theory of general relativity. And even Einstein modified his theory when he first applied it to the universe. He added a "cosmological constant" to counteract an apparent instability. Later, when it was found useless, he discarded it. Maybe we need it back again.

Harrison believes it should at least provisionally be retained, and points out an interesting analogy. In going down five orders of magnitude in size from atoms to elementary particles, electromagnetic theory becomes inadequate and must be supplemented by a theory of weak and strong interactions. Why then, without proof, can we assume in going up five orders of magnitude from galaxies (where we assume general relativity is valid) to the universe that general relativity remains valid? The theory eventually breaks down as density increases. Does it also break down as we increase in size? Obviously we have an uncertainty, not only in our measurements but also in the theory we are applying.

Assuming that general relativity is valid, we have a closed universe that eventually collapses, or an ever expanding open universe. Let's look at the "end of time" in each case. If the universe expands forever, the galaxies get farther and farther apart until finally they are infinitely separated. This means that for us, there will only be one galaxy left — our Milky Way. By this time, of course, there will be little left of it — only dead matter and small red stars. Our Earth will be long gone.

If this is hard to visualize, the alternative is even more confusing. If the universe eventually collapses in on itself, it may seem at first that the end state will be an empty universe with all the matter collapsed into a *singularity* — a region where physical laws do not apply. But this is not so. Remember it's the entire universe collapsing — *space and all*. This means that after the collapse takes place, nothing will be there!

If the universe is oscillating, and if the constants of physics are different after each big bang, there is no reason to think that anything would be like it is now. Stars — as we know them — might not be able to form, and very different sizes and time scales could rule out the formation of galaxies or anything in the new universe that human beings could recognize. It is, in any case, highly unlikely that we will ever know the answer. Artwork by Mark Paternostro.

According to our present theories, this collapse should continue forever with our universe getting ever smaller — a strange ending. But is it really the end? Princeton physicist John Wheeler and others have pointed out that we can only use Einstein's theory of general relativity to watch the collapse so far; beyond a certain point it no longer applies. By this time, the universe is so small that we have to look to the branch of physics that deals with atoms — specifically their structure and interaction with each other, and how they radiate — which is known as a quantum theory. Somehow we must incorporate this into our cosmology to discover what happens.

It's interesting, however, to speculate. Just as our universe has alternatives, so, too, does collapse have two alternatives — at least as far as we know. It can collapse forever, or it can "bounce".

Let's look at the details of this bounce in a speculative manner. As the universe gets continually more dense, it finally reaches a point somewhere around a density of 10^{100} grams per cubic centimeter, where the pressure buildup is so great that a sudden outward expansion takes place. This would constitute an expansion phase similar to the one we are now in. Eventually it too will slow down, stop and collapse. The universe will continue to oscillate back and forth through expansion and collapse phases. This is referred to as the *oscillating* or *pulsating* model of the universe.

Will the phases all be exactly the same? Wheeler has looked closely at this question and come up with some interesting results. The universe is in the quantum realm just before bounce, and Wheeler realized he needed a properly quantized theory for a complete solution. Since no such theory was available, he applied the basic ideas and principles of quantum theory without detailed mathematical analysis.

One of the most important of these principles is the Uncertainty Principle, which tells us that as we try to simultaneously measure such things as position and momentum, we run into problems. As we narrow in and pinpoint one, the other becomes fuzzy and indistinct. Stephen Hawking of the University of Cambridge assumed that a similar phenomenon occurs when the universe collapses to a sufficiently high density. According to his ideas, such things as electron mass and electron charge will become fuzzy. In fact, all fundamental constants such as the speed of light and *Planck's constant* may be lost down the singularity. (Planck's constant is a proportion relating the amount of energy that can be had by radiation to the frequency of that radiation.) When the universe bounces back, these constants will emerge numerically different. If this is the case, we may have new elementary particles of different mass and charge; other fundamental constants will also be different. Hawking has also shown that there is a fuzziness or uncertainty associated with the breakdown of general relativity that we may never be able to penetrate. (He refers to this as the Principle of Ignorance.)

What effect could this have on the universe? It may mean that the cycles are of different lengths. Our cycle will last approximately 80 billion years, according to Sandage, but there may be some that last even longer, and some that last only a few million years. That corresponds to a universe only a

Space is so vast that we can hardly imagine its scale. At right is the spiral galaxy NGC-7331 — terribly remote from our own galaxy by any human standards. To the left is a cluster of dozens and dozens of galaxies including spirals similar to NGC-7331, but some 50 times more remote. Hale Observatories photographs.

few million light-years across. It would hardly be large enough for our galaxy; a universe this small wouldn't have much room for galaxies.

If this seems strange, consider another aspect. Life as we know it here on Earth took about four billion years to develop. This is also likely the case elsewhere in the universe (assuming life exists there). This means that a universe with a maximum radius of only a few million light-years could not contain life, as it would not have had enough time to develop.

Our universe may indeed be much stranger and puzzling than we think. Brandon Carter of Cambridge University recently showed how true this is, when he examined the effects of small changes in the fundamental constants on stars. Very small changes have a profound effect. A slight change in one direction would allow only small red stars to form. Yellow stars like our sun would be impossible in this universe. A slight change in the other direction would allow only large blue stars to form.

This means even if the cycle were sufficiently long to allow life to form, it might not. We know that life needs yellow stars like our sun. They have ideal life zones and a life cycle long enough for life to form. If they don't exist, it is extremely unlikely that life could form.

It seems that life in our universe is "finely tuned" to the fundamental constants it now has. A slight shift in either direction and we're "tuned out". This had led Wheeler to conclude that life may be exceedingly rare in our universe. Indeed, we may be the only life.

It may be difficult to share this opinion. But admittedly there are so many strange coincidences and improbabilities that we might be led to believe the universe was tailored just for us. On the other hand, the odds seem so overwhelmingly great that there's someone here besides us.

Wheeler made another interesting point: Assuming the universe is oscillating through cycle after cycle with some (possibly most) of the cycles not suited for life, we might wonder what good the cycles are with no life — millions, possibly billions, of years passing with no one to make use of it, no one to even see it. What sense does it make — or is it even supposed to make sense? Maybe questions like these are beyond our comprehension, but at least they're interesting to speculate about. Man will never cease to wonder, to ask questions, and to probe the unknown. Even if there is little chance of a clear cut answer, or even if the answer has little relevance to us in the 20th century, we cannot help but wonder.

As we have seen, the end of time is difficult to comprehend. It can come in several forms — an almost empty space, void of all galaxies except our own, or the strange situation where there is no space at all. It is possible it will go on cycle after cycle with new galaxies and new worlds being generated in each new cycle — but many and even possibly all of these cycles may pass without life in them. Life is delicate and strange; it may be tuned only to the universe it is in.

STELLAR FRONTIERS

Can Life Evolve in Elliptical Galaxies?

by
John Gribbin

The puzzle of the origin of life — where we came from and how we got here — has taxed humanity since the beginnings of self awareness. On the time scale of man's history, it is only very recently that any real answer to the puzzle — one that we can test against observations — has been reached. We now see that the origin of life and the emergence of man and other species are intimately linked to the history of Earth and of our solar system — for, of course, life as we know it depends on a planet for a home and energy from a star.

In the past few years, the link between man and his immediate surroundings in space has proven even stronger than previously realized. The origins of the sun and solar system may themselves be intimately linked with the structure and origin of the Milky Way galaxy. Using hindsight, this seems logical and straightforward enough. But new discoveries have dramatic implications on a cosmic scale. Our galaxy is a fairly typical spiral, and its structure is therefore quite different from ellipticals (the other main family of galaxies). And, if the origin of life depends on the nature of our solar system — which in turn depends on the structure of our home galaxy — it may be that life as we know it cannot exist in elliptical galaxies.

Creatures like ourselves require air and water, winds, oceans and land; we have evolved to suit the particular arrangement of these physical properties of our planet. Modern astronomical ideas give us a fairly good idea of what things must have been like at Earth's beginnnning, as well as an outline (at least) of how our planet has since developed. The story of a changing Earth begins more than five billion years ago, with the formation of the solar system from a cloud of dust and gas in interstellar space. But even knowing this is not enough; we must turn and look at the galaxy itself.

Our Milky Way contains about 100 billion stars; most are concentrated in a thin flat disk about 100,000 light-years across and 2,000 light-years thick. The spiral pattern that gives its name to our class of galaxies is a feature of this disk. This pattern was found in many other galaxies long before it was identified in our own. In fact, trying to unravel the structure of our own galaxy from *inside* exemplifies the "problem" of finding the forest obscured by trees.

Spiral patterns come in a wide variety: Some galaxies have tightly wound "arms" of stars and dust coiling outward from the central regions; others are more loosely twisted. In some spirals, two main arms dominate the pattern; in others there is more confusion, with a messy — though recognizable — spiral pattern. Furthermore, the spiral patterns seem to be rather permanent; if they weren't, we wouldn't see them in so many neighboring galaxies.

Having seen the spiral patterns in other galaxies, observational astronomers began to map the spiral arms of our own galaxy in the 1940s. By then,

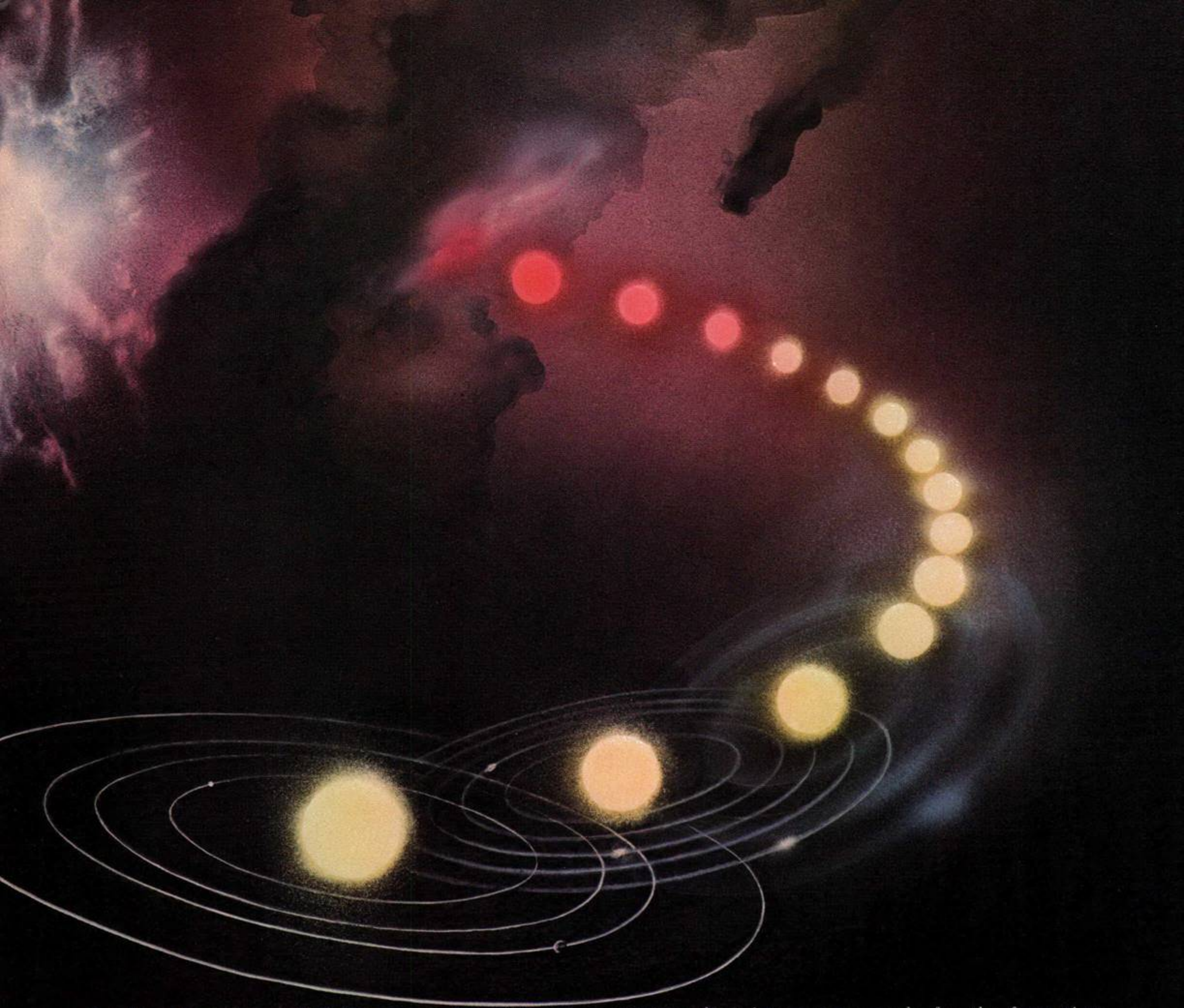
A giant even among the giant elliptical galaxies, M-87 in the heart of the Virgo cluster of galaxies may not harbor life-bearing planets or any living things. What are the conditions necessary for the appearance of life in a galaxy? How can the elements necessary for life come into being if the original big bang did not create them? Hale Observatories photograph.

studies of spiral structure in other galaxies had shown that certain types of young stars (O and B stars) are common in spiral arms and can be used as *tracers*. It's as if some of the trees in our galactic forest are specially marked, and can be used to trace a twisting path (the spiral pattern). Later, with the advent of radio astronomy, and with the discovery that interstellar gas clouds also concentrate along the spiral arms, it proved possible to map regions of hydrogen gas concentration in both our own and other galaxies. Today we have a fairly good idea of what our galaxy would look like to an observer in another nearby galaxy.

The nucleus of our galaxy's center is a collection of stars bulging out like a fat lens — or like an elliptical galaxy — about 5,000 parsecs (16,000 light-years) across. Surrounding it is a thin disk of stars, stretching much farther and containing the spiral structure. At the present position of the solar system, this disk is about 600 parsecs (8,000 light-years) thick which, at 10 kiloparsecs (32,000 light-years) from the center, is on the outer fringes of the spiral armed disk. A faint "halo" of old stars and globular clusters surrounds the whole disk/nucleus system, stretching across a spherical volume of space, perhaps to very great distances. The halo is very dim, and thus does not appear obvious on photographs of other spirals. Studies of the nearby spiral galaxy M-51 have shown that it has an "envelope" covering at least 110,000 parsecs (360,000 light-years), and there is no reason to expect our galaxy's halo to be less extensive.

To a star like our sun, well away from the nucleus and clearly embedded in the disk, the spiral structure determines the "local" environment. While stars in the halo and nucleus of spiral galaxies are old (they were formed at the time their galaxies first formed), the stars of the spiral arms and disk are basically younger, "second generation" stars — formed after the basic pattern of the galaxy was laid down. This may be all-important for the existence of our solar system and ourselves.

The sun and solar system were produced by the collapse of a cloud of dust and gas within the over-

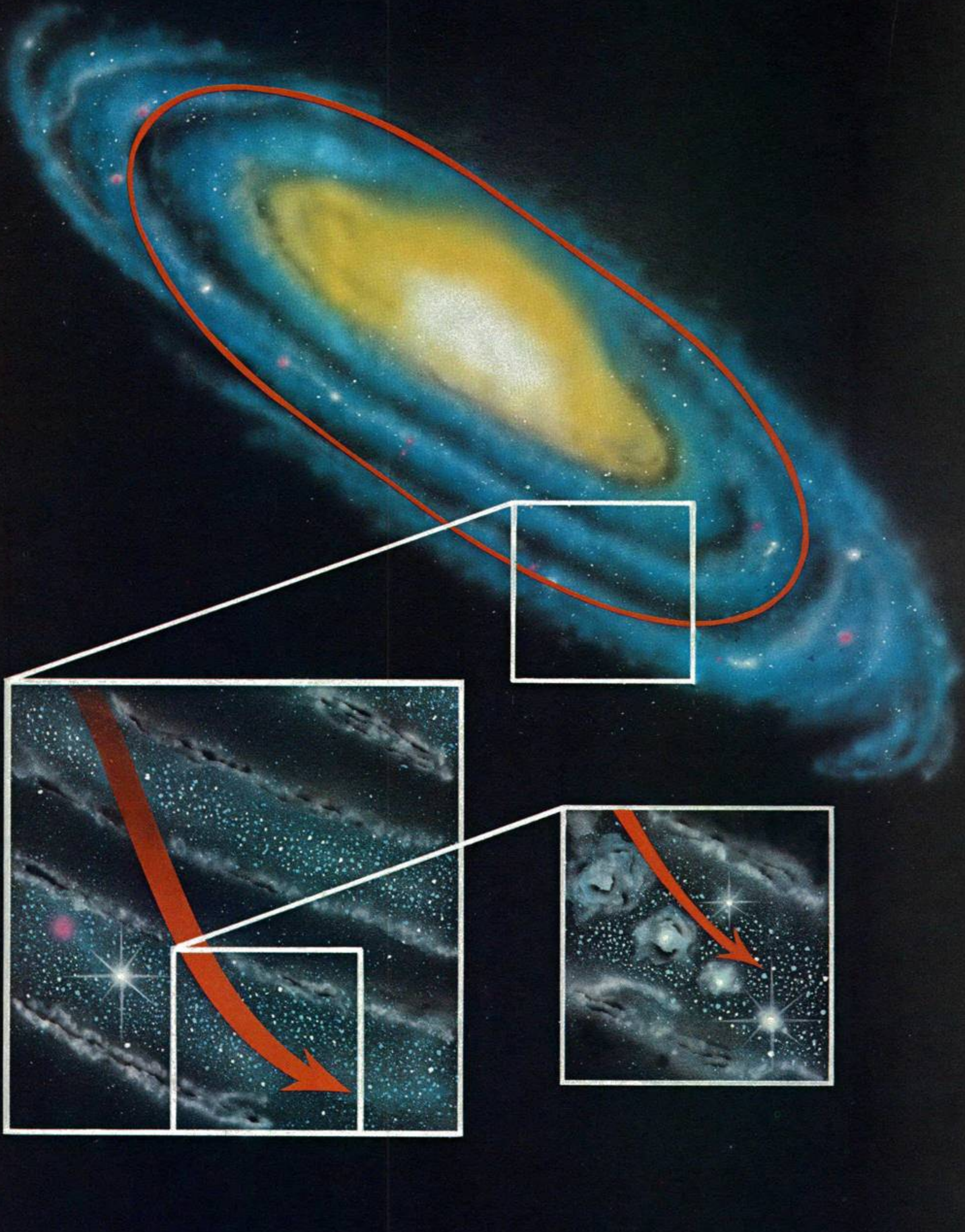


Crucial to the existence of life (as we know it) are "heavy" elements such as carbon and oxygen. The first stars were condensed from hydrogen and helium only — no heavy elements were created in the big bang. Hence, they could have had no dense rocklike planets or life. In the spiral arms of galaxies, the debris from supernovae — which manufacture the heavy elements in their cores — recondense to form stars with planets and the materials necessary for life. Elliptical galaxies lack spiral arms that recondense heavy element-enriched interstellar gas, and hence may contain no lifebearing planets. Artwork by Ernest Norcia.

all framework of the spiral pattern. We can detect such clouds today, emitting strongly at infrared frequencies as they begin to warm up during collapse (see "Birthplaces of Stars", ASTRONOMY, October 1976). But these clouds are already relatively dense, by the standards of interstellar space. Before the process of star formation can begin, the more ordinary tenuous interstellar clouds must have been swept up and compressed in some way. Scientists now understand — at least in outline — the process of just how the spiral pattern of our galaxy can act to sweep up ordinary interstellar clouds and presqueeze them into a state ready for the formation of stars and planets.

On many pictures of spiral galaxies, you can pick out disk structure in two ways: by tracing the bright stars of the spiral arms, or by following the line of dark material which seems to edge the bright arms. Although less obvious to the naked eye, the dark lanes of dust (accompanied by clouds of cool gas revealed by radio techniques) are the true, permanent features of the spiral structure. The spiral pattern is seen as a kind of standing shock or blast wave, producing these dark regions as compression lanes through which all the material of the disk is squeezed as it orbits the nucleus.

For practical purposes, it doesn't matter if we assume that the compression wave is standing still while everything in the disk orbits around and through it, or if we imagine the stars, gas and dust of the galaxy being overtaken and swept up by the compression wave as it twists around the disk. The effect is the same either way: Any cloud of gas and dust in the disk will pass through such a compression



Cosmic gas clouds, stars and supernova debris all orbit the center of the galaxy in irregular circular or elliptical patterns. Twice during each revolution, as a gas cloud passes through the spiral arms, it is compressed a bit. Finally, the gravitational attraction of the gas cloud takes over for itself. The cloud then collapses to form a new generation of stars enriched in heavy elements by supernova debris mixed into the interstellar gas. The upper view shows a spiral galaxy, with the orbits of typical stars and gas clouds through it. The first enlargement shows their orbits crossing the spiral arms, and the second enlargement represents a cloud as it passes through a zone of compression (the dark lane along the inner edge of the spiral arm) and subsequently collapses to form a second generation star in the spiral arm. Artwork by Michael Boelke.

lane twice in each orbit of the galactic center — once for each main arm. Each time it squeezes through the compression zone, the cloud is condensed a little more, until eventually it reaches a density where its own gravity can take over to produce continued collapse until a star (or several stars) is born.

At the distance of the solar system from the galactic center, it takes about 200 million years for a star to complete one orbit of the galaxy. That seems to be a long time, but it means that the sun and its family of planets have been around the galaxy only 20 times since the solar system formed about five billion years ago. Before that, the cloud from which the solar system formed must have followed the same orbit for at least hundreds of millions of years.

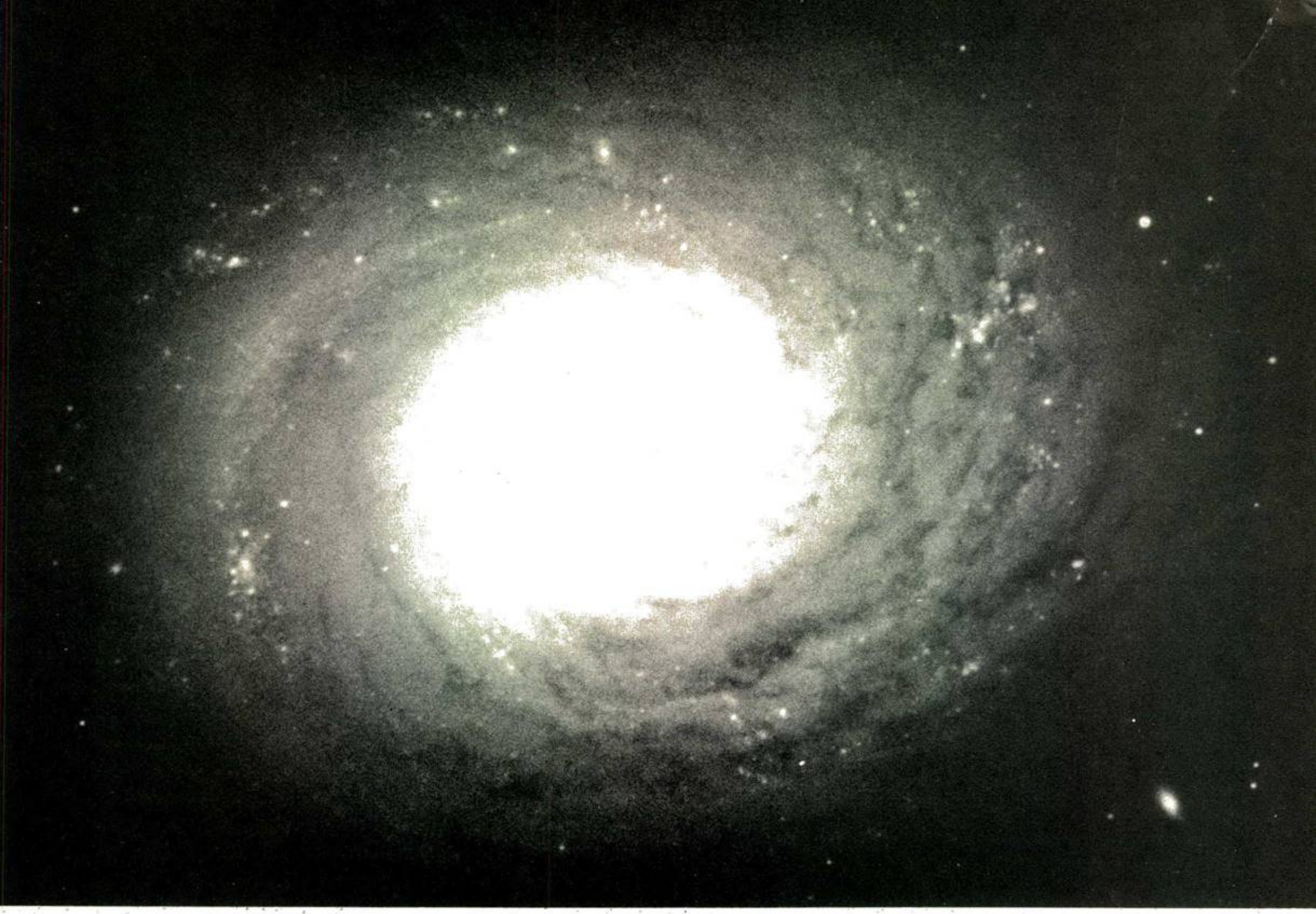
This repeated squeezing may trigger the production of everything from comets to loose clusters of stars, depending on the size of the cloud being squeezed and the strength of the compression zone of the spiral arm. Between those extremes, the usual product of a typical squeeze of an ordinary cloud will be a few stars and some miscellaneous rubble. Those few stars soon separate as they continue orbiting around the galaxy, each carrying its share of rubble in the form of a family of planets. Later in the history of the solar system, other encounters with dust lanes and compression zones in spiral arms could have had dramatic short term effects, perhaps explaining the origin of ice ages (see "Dust Clouds and Ice Ages", ASTRONOMY, April 1976). Once there was a planet to live on and a star to provide energy, life could begin to evolve along the lines that have produced the variety we see today.

To find out what the primitive Earth was like just after it formed requires the combined efforts of geologists, geochemists, geophysicists, astronomers, biologists and chemists. The first thing the combined viewpoints of all these sciences tell us is that Earth's present atmosphere is very different from the original atmosphere. Helium and other so-called noble gases (such as neon, xenon and krypton) are far less abundant on Earth than in interstellar clouds, and it seems clear that much of the original nebular gas was lost as the planet formed — implying that Earth's first atmosphere was produced by chemical reactions in rocks, and volcanic action. This atmosphere would have been composed chiefly of water, carbon dioxide, carbon monoxide, nitrogen, hydrogen chloride, hydrogen and sulphur — the same gases released by volcanos and hot springs even today. Microfossils found in rocks more than three billion years old confirm the existence of both life and an atmosphere long before there was any free oxygen in our air. These first steps on the evolutionary ladder would have begun in the warm oceans of the young Earth, rich in molecules essential to life.

We now know that these molecules combine readily to produce amino acids under conditions like those on primitive Earth. In fact, we know that the "soup" of molecules in interstellar clouds contributes even more complex molecules than the simple "starters". For example, formaldehyde — now identified as a constituent of interstellar clouds — is a forerunner of sugars; cyanoacetylene, also found in just the kind of clouds from which stars and planets form, leads to the buildup of molecules that in turn are essential to production of DNA, the life molecule. A warm ocean, with large amounts of the kinds of compounds common on Jupiter even today, and a lacing of more exotic organic molecules such as formaldehyde and cyanoacetylene, energized by lightning discharges and ultraviolet light from the sun, could hardly be a better place for the first living molecules to form.

But all this, of course, depended on the presence of those essential starting materials in the interstellar clouds. And the elements from which those compounds were themselves built up can only have been created in the "insides" of stars. The basic material of the universe, following the big bang, was a mixture of hydrogen and a lesser amount of helium. We know this from studies of old stars, which were presumably created from this original universal gas. But the primordial gas was extremely deficient in all elements heavier than helium; there certainly were not enough heavy elements to form rocky planets. All the elements we see around us, the atoms of our bodies and the air we breathe — everything except hydrogen and helium — has been created since the universe exploded outward from the big bang. With modern theories of nuclear physics we can understand how such a thing is possible, since heavy elements can be built up by fusion of the lighter elements under the right conditions.

The right conditions are just those found in stars. In 1957, astrophysicists Margaret and Geoffrey Burbridge, William Fowler and Fred Hoyle published a paper in which they showed that nuclear "cooking" in stars could indeed produce the variety of elements we see today — provided that the heavy elements, once created, were scattered through space in stellar explosions. (This explanation of the origin of the elements was one of the most important scientific developments of the time, and one which surprisingly received little attention.) But here is the key to the whole mystery of life. First generation stars, containing only hydrogen and helium from the big bang, build up heavier elements through nuclear fusion. These elements are spread through space in stellar explosions and gather in clouds where quite complex compounds can build up. The density waves in a spiral galaxy arm recompress this tenuous gas, until these clouds collapse into new stars, richer in heavy elements. And the process can be repeated, with still more hydrogen and helium being converted into more heavy elements. Clearly there could be no planets like Earth if there were no heavy elements like iron, oxygen, sulphur or carbon — nothing but hydrogen and helium. And so, the



Dust lanes define the spiral arms of the galaxy NGC-4736 (M-94) in Canes Venatici. Can life evolve in spiral galaxies? We think it does, for in spiral galaxies the debris from each generation of stars is swept up in the arms and recompressed into new stars enriched in heavy elements — new stars circled by planets made of heavy elements on which life can evolve. Hale Observatories photograph.

first generation stars in our galaxy (the old stars of the halo and nucleus) must be devoid of Earthlike planets. There may be Jupiters and Saturns, Uranuses and Neptunes, but nothing like Earth, Mars, Mercury or Venus.

This is a very dramatic discovery indeed. Old time science fiction writers who like to place the oldest and wisest races of our galaxy on planets circling the oldest stars have had the rug pulled from under them. But the implications go far deeper than that.

As we have seen, once the heavy elements are created in the first stars and spread through space, their reprocessing into second generation stars with attendant planets seems to depend crucially on repeated compression produced by the spiral arm shock wave. Without this spiral wave of compression, first generation stars might have formed during the processes that formed the galaxy, and they could still fuse light nuclei of hydrogen and helium repeatedly to produce heavy elements. Indeed, they could still explode and scatter those elements through space and into gas clouds where molecules such as formaldehyde could build up. But there would be no way in which these clouds could be squeezed into a state ready for the formation of second generation stars and their families of Earthlike planets.

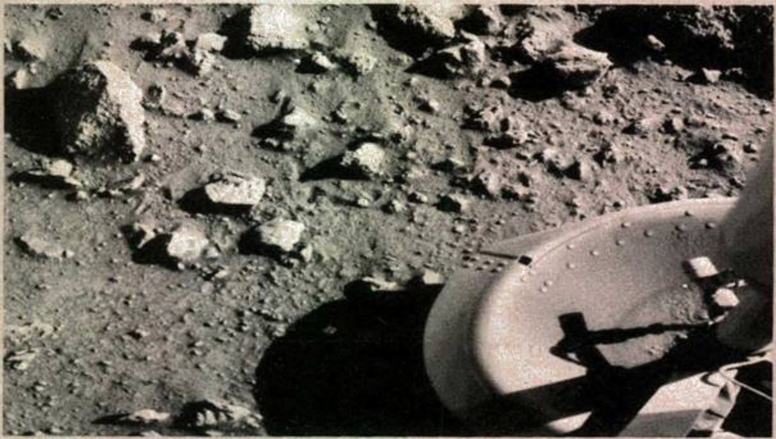
This is just the situation we find in elliptical galaxies — no dark compression lanes, no spiral arms, no second generation stars and, by implication, no Earthlike planets. There seems to be no escape from the conclusion that life *as we know it* could never have evolved in any elliptical galaxy.

But there is still room for imagination. Life "as we *don't* know it" could exist even in our own solar system, on the giant planet Jupiter where there is an abundant supply of the necessary molecules for life to begin, plus some solar energy and some internal warmth. Perhaps in some distant elliptical galaxy, a great cloud of dust and gas, rich in heavy elements from stellar explosions and undisturbed by any spiral arm compression waves, has been left almost undisturbed for thousands of millions of years — long enough, even in the cold of space, for molecules far more complex than even formaldehyde to have built up.

John Gribbin is a British science writer who spent five years on the staff of ***Nature****. This article draws partly on material from his recent book,* ***Our Changing Planet****, published in London by Wildwood House.*

ASTRONOMY *is*. . .

exploration



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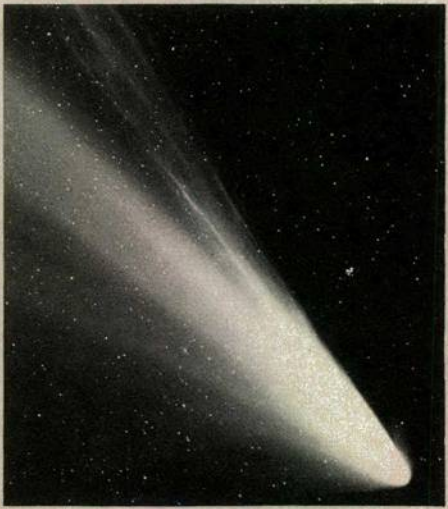

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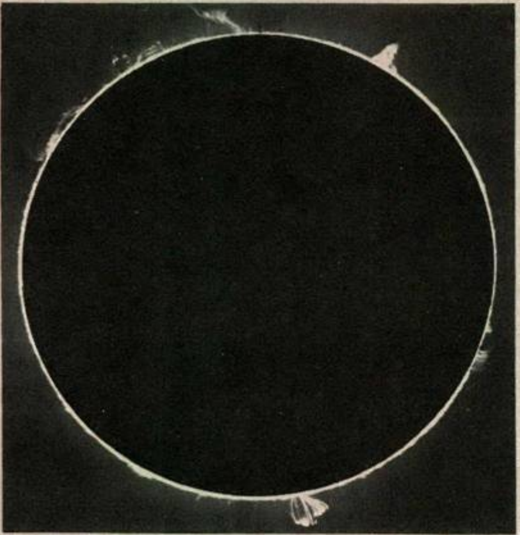

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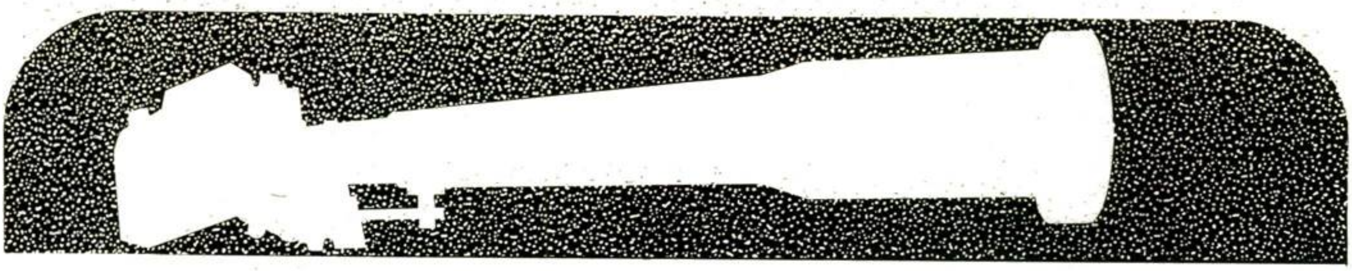


PHOTOGRAPHY IN ASTRONOMY

Vacation and Travel Astrophotography

by
Richard Berry

Each year vacationers head off into the mountains, to the tropics, the beach, the far North — anywhere to "get away from it all". People usually want to escape from cities, smog and the glare of lights. On vacation, you may rediscover the stars. In a new environment, you may find yourself looking up and seeing a dark sky for the first time in months; some of you may see stars well for the first time in your lives!

Being away from cities and crowds will let you see the natural unpolluted sky: a trip to southern latitudes may reveal new constellations and stars, while a vacation in the north may bring the ghostly display of aurorae. The first thing you'll want to do is *look*: to learn the new stars, to experience an aurora, to get used to seeing the Milky Way dominating the sky. Perhaps you'll want to bring some of it back with you, and you'll get your camera out. But then what?

Stationary Camera Exposure Times

Lens Focal Length (mm)	0° to 30°	30° to 60°	Polar
28	20 sec.	25 sec.	30 sec.
35	14 sec.	20 sec.	25 sec.
50	10 sec.	14 sec.	20 sec.
85	7 sec.	9 sec.	15 sec.
135	4 sec.	6 sec.	10 sec.

The exposures given will show slight trailing under high magnification. Trails are not objectionable unless you use at least twice the tabulated time.

Piggyback Cameras — Allowable Guiding Lapses

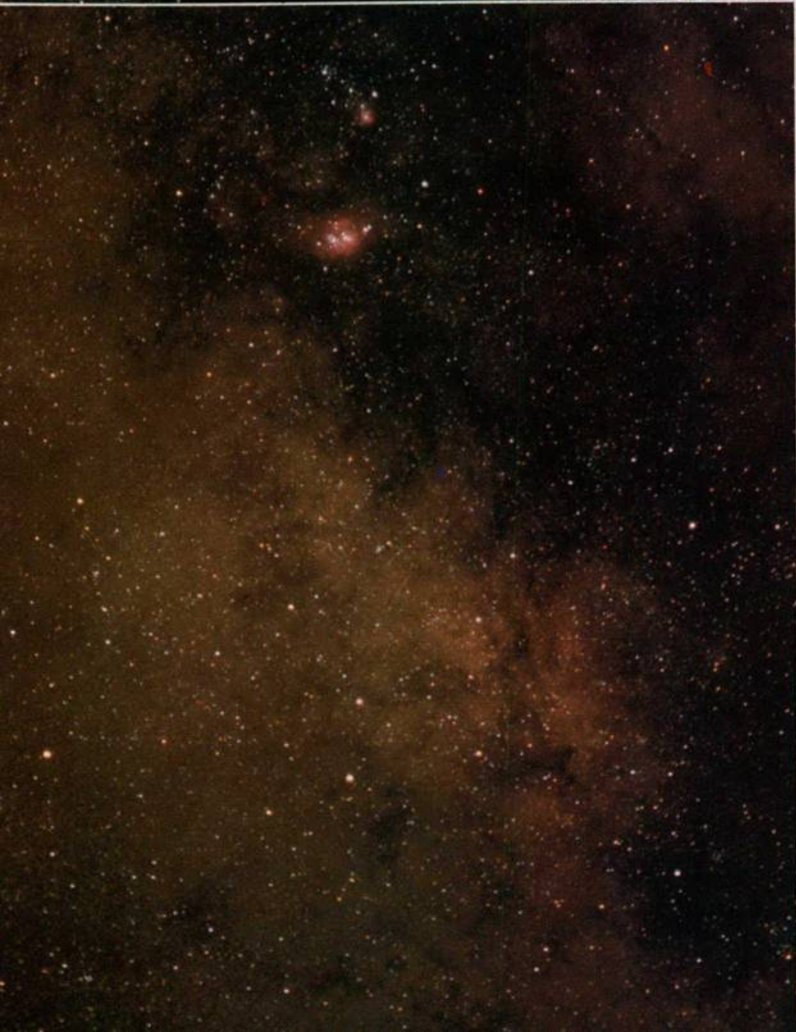
Lens Focal Length (mm)	0° to 30°	30° to 45°	45° to 60°	Polar
28	15 sec.	20 sec.	30 sec.	30 sec.
35	12 sec.	17 sec.	25 sec.	25 sec.
50	8 sec.	11 sec.	15 sec.	15 sec.
85	5 sec.	7 sec.	10 sec.	10 sec.
135	3 sec.	4 sec.	6 sec.	6 sec.

Portability is crucial. How much equipment *can* you carry with you, and how much equipment do you *want* to carry with you? If you are flying to Alaska in a small airplane, you might be limited to a single camera. But if you go camping with a trailer, several hundred pounds of telescope and accessories may be no problem at all.

The simplest equipment you can take is a camera — and almost any will do. You can readily photograph star trails above mountains, cacti, palm trees, the Pyramids, etc., simply by balancing the camera firmly on a nearby rock, jeep or whatever happens to be handy, and exposing for five minutes or more. If you want to get steady well-framed results, though, be sure to bring along a tripod. You are then free to set the camera where you want it instead of on rocks that may not be placed for the best picture. Even inexpensive Instamatic cameras with time exposure capability work quite nicely for this type of picture, although such cameras usually show the foreground Pyramids or mountains as silhouettes. Cameras with large, fast (f/2.8 or faster) lenses will usually reveal detail in the foreground during a star trail exposure. In either case,

Upper left: Star trails are easy! This 10 minute exposure on High Speed Ektachrome required only camera, tripod, cable release and fast film. Photograph by Mark Erickson. Lower left: Light portable equipment was all that was needed for a five minute exposure of comet West on GAF 500 with an f/2 lens of 55mm focal length. This photo was taken from a dark site in Henry Coe State Park in California. Photograph by Ernest Piini. Top right: From Puerto Rico (at latitude 18 degrees north), a 30 second exposure caught the Southern Cross and Eta Carinae nebula above tropic clouds and palm trees. This shot was taken on GAF 500 film with a 55mm f/1.4 lens. Photograph by Wayne Wooten. Center right: From Churchill, Manitoba on Hudson's Bay (59 degrees north latitude), a spectacular aurora and setting Venus hang over the icy landscape. The camera was balanced on a rock; exposure was 10 seconds at f/2 on Agfachrome 50 film. Photograph by William Morrow. Bottom right: This dawn scene shows the *moon*, *Venus and* Mercury above the 60 inch Solar Telescope at Kitt Peak National Observatory. This was a 30 second exposure at f/2, taken on High Speed Ektachrome. Photograph by Fred Espanak.

Left: Taken from the pathway leading to the 120 inch telescope at Lick Observatory, a short exposure star trail photo dramatizes the beauty of a visit to a professional observatory. Below: Twilight photos — although not strictly astronomical — are a fine way to begin an astronomical slide show. Photographs by Mark Erickson. Above: On vacation in Arizona, the photographer took advantage of clear, dark skies to capture the Pleiades in a 25 minute guided exposure taken with a 200mm f/3.5 telephoto lens on GAF 500 film. Photograph by David Healy. Opposite, top: Traveling to fine observing sites has become a way of life for serious astrophotographers. Objects like the Milky Way starclouds can be recorded with fast film in approximately 15 to 30 minute exposures. Photograph by Hal Jandorf. Opposite, lower left: With fast, medium focus telephoto lenses, details of the Milky Way and nebulosities may require no more than a 30 minute exposure. Photograph by Charles Townsend. Opposite, lower right: Reaching deep into space from the clear dark skies of North Sandwich, N.H., a 200mm telephoto was piggybacked for a 36 minute exposure on GAF 500 film. Photograph by David Healy.



Exposures for Vacation Astrophotos

	ASA 400+ Films	ASA 100 to 200 Films	ASA 25 to 64 Films
Long Star Trails	10 to 60 min. at f/4	10 to 60 min. at f/2.8	10 to 60 min. at f/2 or f/1.4
Short Star Trails	2 to 5 min. at f/2	2 to 5 min. at f/2	2 to 5 min. at f/2*
Stationary Camera Stars	10 sec. at f/1.4 or f/2	10 sec. at f/1.4 or f/2	15 sec. at f/1.4 or f/2*
Guided Constellation Photos	5 min. at f/2	5min. at f/2	5 min. at f/2*
Milky Way & Deep Sky Photos	40 min. at f/2.8 15 min. at f/2 5 min. at f/1.4	30 min. at f/2 15 min. at f/1.4	60 min. at f/2 30 min. at f/1.4

* Shows markedly fewer stars than faster films

NOTE: These exposures are intended to help you get started; don't rely on them completely. Make trial shots to find the exposure that will give you the very best results.

any exposure longer than five minutes will show suitably impressive trails. If you want long trails, run the exposure 30 to 60 minutes — but be sure to set the aperture of extremely fast lenses to f/2.8 or f/4 if you are using fast films, or you might overexpose the sky background.

Suitable foreground subjects add travel interest to the picture especially if you want to show stars and constellations unfamiliar in your latitude. Table 1 shows the maximum exposures you can use before trailing becomes conspicuous.

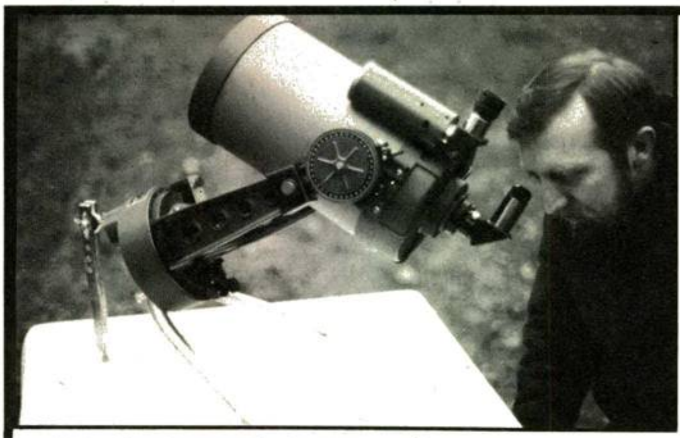
While camera and tripod are the minimum vacation astrophotographic equipment, you might, of course, be able to carry more — especially if your main interest is to escape the glare of city light and photograph the skies. If you can also carry a small telescope with an equatorial mounting, you can try guided long exposure astrophotos. Even the smallest telescope will do for piggyback photography: A one inch aperture, 20 power telescope is more than adequate for guiding your camera with a wide-angle, normal, or short telephoto lens. Before going off into the wilds, though, test the whole arrangement in your own backyard to make sure you haven't forgotten any vital parts. If you have a reasonable amount of patience, you don't even need a clock drive — you can guide entirely by hand. Just as for star trail photographs, if you keep the trails short enough they won't show on the film. Even if your guiding is not absolutely continuous or perfect, rest assured there is a large margin for error. When you're guiding a 50mm lens on some high, clear, beautiful mountaintop or tropic beach, you can take off from guiding for up to 10 seconds before your lapse will show. Table 2 lists allowable guiding lapses for different focal length camera lenses.

During the summer, the prime target for guided astrophotography with ordinary cameras is the Milky Way; in fact, the most impressive views of the Milky Way may be those taking in a wide sweep of sky and stars. The brilliant starclouds in Sagittarius, the dustlanes near the red giant Antares, the Lagoon and Trifid nebulae (for which a telephoto lens is best), the starcloud in Scutum, and the magnificent fields in Cygnus will all pose for their protraits. With fast color films (GAF 500, GAF 200, Fujicolor 400, High Speed Ektachrome, and Ektachrome 200), a 5 to 15 minute exposure at f/2 is usually a good trail exposure. If you don't want to guide that long, you'll find two to five minute exposures will do an impressive job of recording stars and constellations although, of course, they won't show the Milky Way quite as well.

While traveling, you may be forced to buy the film you'll use from drugstores or souvenir stands, and you might regret it. Such film has often been stored under poor conditions for a long time and may have lost sensitivity and color balance — not enough to harm daytime travel scenes, but enough to hurt its ability to record stars and nighttime objects. If possible, buy your film from a reliable camera store before you go and keep it cool while traveling — never leave it in a glove compartment during summer! When you return, send it to a reliable processor. If you fly, don't let it go through x-ray machines. While x-rays don't damage ordinary pictures, they do fog fast films enough to degrade the sky background. You can very politely ask for a hand search of your camera bag.

No matter where you go — be it halfway around the world, to the mountains an hour's drive away, to the north on business, or the south for pleasure — have a good time, and keep an eye on the stars!

Top: At an 8,000 foot elevation, the clear skies make Timberline campground on the southern slope of 12,000 foot Mt. Adams worth the visit. When clouds interfere with guided exposures (note the breaks in the star trails), you can always try star trails. This 15 minute exposure was taken at f/1.7 on GAF 500 film. Photograph by Jim Kousbaugh. Bottom: Southern stars turn slowly above Inca ruins in this one hour exposure on High Speed Ektachrome film, taken with a 50mm f/2.8 lens. The ruins were lit with an electronic flash during the exposure. Note that the south celestial pole lies almost exactly on the horizon. Photograph by Marco Hellman.



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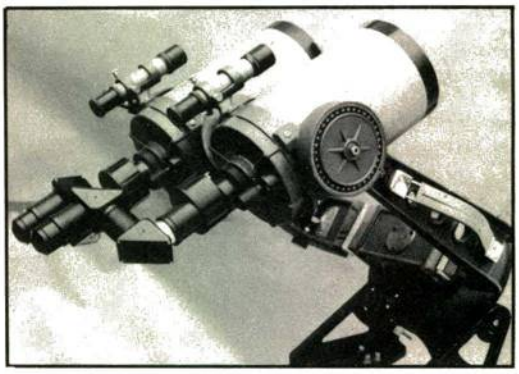

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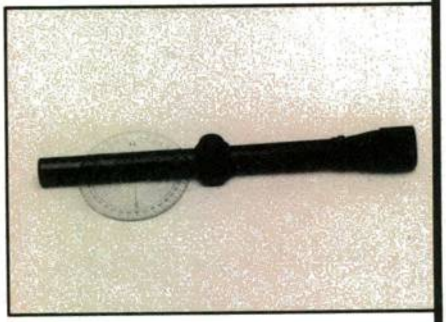

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Planets Group in May Sky

As nights grow gradually warmer through the spring months, the brighter planets leave the evening sky one by one. In May, as Jupiter approaches conjunction with the sun, it disappears into the evening twilight, while Saturn drops nearer to the western horizon. Observers interested in planetary phenomena must switch their attention to the morning sky for an occultation of Venus by the moon and a close approach of the brightest planet to much dimmer Mars.

Venus

At magnitude -4.2, Venus reaches greatest brilliancy for the second time this year on May 11. Located in the dim constellation Pisces, Venus rises about two hours before the sun during most of the month. Its phase grows from a thin crescent at the beginning of May to a fatter, almost half-phase, crescent by month's end. Having passed inferior conjunction in April, Venus is now moving away from Earth; its distance from us increases from 34 million miles (55 million kilometers) to 54 million (87 million).

Observers in central Canada will witness an occultation of Venus by the moon on the morning of May 14. For those in locations farther east, this event will take place in daylight; for west coast observers, it will already have ended by moonrise. Nowhere in the United States will a full occultation be seen, but observers in the extreme northwestern tip of North Dakota or the northeastern section of Montana will see a parial occultation. Elsewhere, Venus will pass very close to the waning crescent moon, but will not be covered by it. Nevertheless, this close passage is itself quite worthy of observation, presenting a beautiful sight in the morning sky — eminently suitable for photography. ASTRONOMY encourages photographers throughout North America to capture this event on film; a comparison of photos from many different locations may be the subject of a short feature in a future issue if enough are received.

All the interesting Venus events in May take place within a few days of each other! On the morning of May 13, Venus will be located about 1.4 degrees north of Mars. If you've been unsuccessful so far this year in locating the red planet, this conjunction will provide an ideal opportunity for you to do so, as the two planets will be in the same field in binoculars or low power eyepieces. Mars, at magnitude +1.3, is about 1/100 as bright as Venus. However, a first magnitude object is usually easy to locate, and the two planets close together will be a pretty sight.

Mars

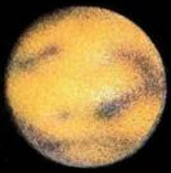
Located in Pisces, Mars can be found low in

This photograph of a region near the lunar north pole was taken through the 42 inch (106 centimeter) telescope of the Pic du Midi Observatory in France. At upper left is Lacus Mortis, enclosing the crater Bürg. The two prominent craters at right are Eudoxus (top) and Aristoteles, the latter abutting on the outlying section of Mare Frigoris. Note the "wrinkles" in the mare surface, which are probably lava frozen in midflow. Photograph by Jean Dragesco.

Planet Finder

Ⓒ Ceres

May	1	15
R.A.	12^h13^m	12^h10^m
Dec.	+14°07'	+12°56'
Mag.	+7.3	+7.5

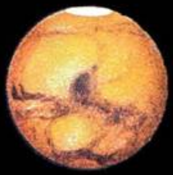


Ⓐ Mercury

May	1
R.A.	2^h27^m
Dec.	+14°58'
Mag.	+3.3

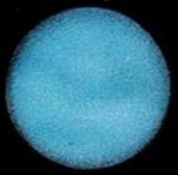
Ⓑ Mercury

May	15
R.A.	2^h14^m
Dec.	+10°22'
Mag.	+1.5



Ⓜ Mars

May	1	15
R.A.	0^h14^m	0^h53°
Dec.	+0°13'	+4°28'
Mag.	+1.3	+1.3



Ⓝ Neptune

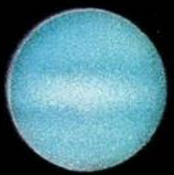
May	15
R.A.	16^h56^m
Dec.	-21°06'
Mag.	+7.7

SUN

The sun is within the stippled zone throughout the month. Planets and stars near this area are not easily seen.

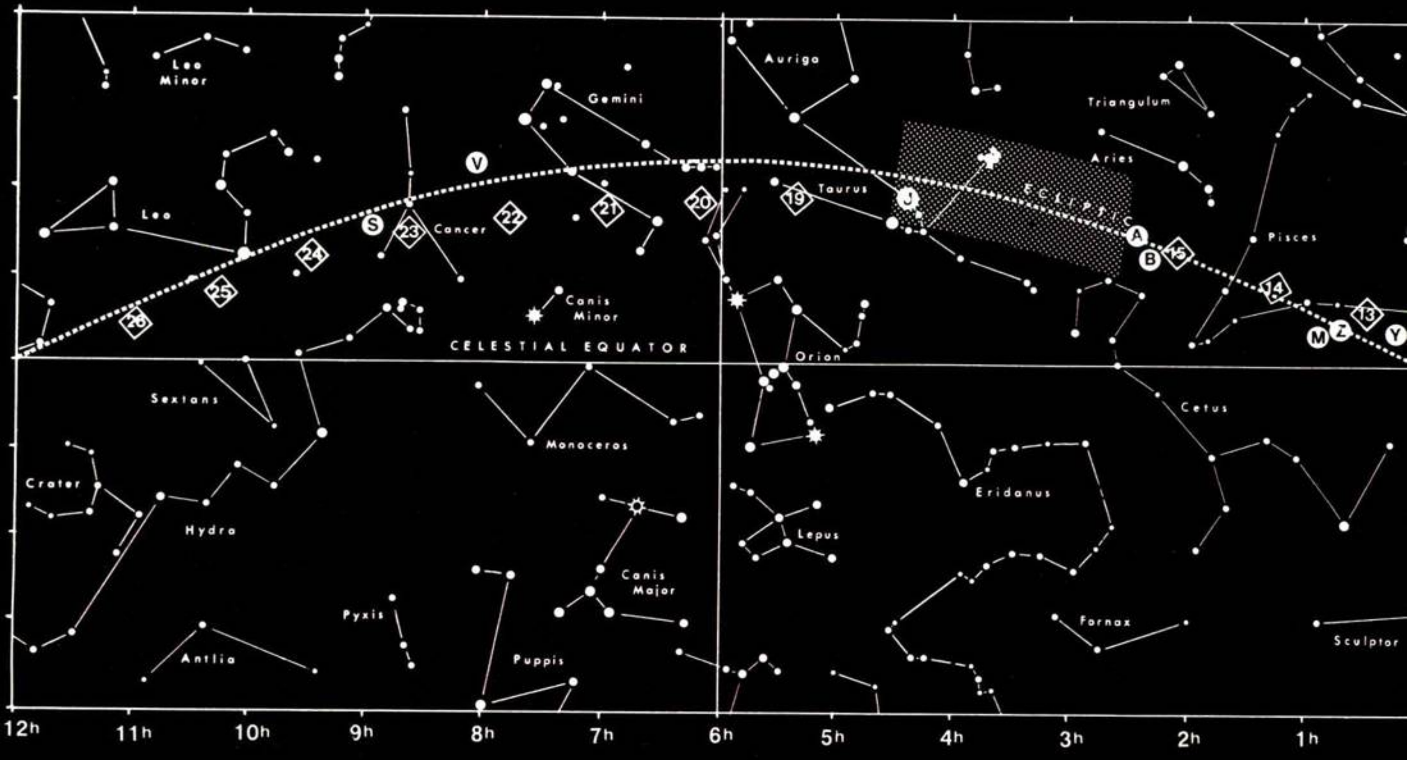
Ⓢ Saturn

May	1	15
R.A.	8^h52^m	8^h55^m
Dec.	+18°35'	+18°24'
Mag.	+0.5	+0.6



Ⓤ Uranus

May	15
R.A.	14^h27^m
Dec.	-14°06'
Mag.	+5.7

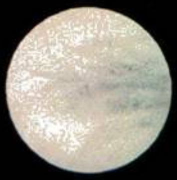

Leo Minor
Gemini
Auriga
Triangulum
Aries
Leo
V
S
Cancer
23
22
21
20
19
Taurus
J
ECLIPTIC
A
B
15
14
13
Pisces
M
Z
Y
24
25
26
Canis Minor
CELESTIAL EQUATOR
Orion
Sextans
Cetus
Monoceros
Crater
Eridanus
Hydra
Lepus
Canis Major
Pyxis
Fornax
Sculptor
Antlia
Puppis
12h
11h
10h
9h
8h
7h
6h
5h
4h
3h
2h
1h

The chart shows the positions of the moon, planets and brightest asteroids for the current month. Letters within the circles correspond to the letters beside each object in the data section above the map. Additional information about each object is given there. R.A. = right ascension and Dec. = declination, the two coordinates used to locate astronomical objects. The general coordinate system is indicated around the edge of the map. Mag. = magnitude, a

May 1977

Ⓥ Vesta

May	1	15
R.A.	7h40m	8h01m
Dec.	+25°07'	+24°20'
Mag.	+8.2	+8.3



Ⓙ Jupiter

May	1	15
R.A.	4h16m	4h30m
Dec.	+20°46'	+21°18'
Mag.	-1.5	-1.5

Ⓨ Venus

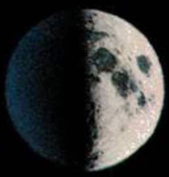
May	1
R.A.	0h28m
Dec.	+5°24'
Mag.	-4.2

Ⓩ Venus

May	15
R.A.	0h52m
Dec.	+5°16'
Mag.	-4.2

Ⓟ Pluto

May	15
R.A.	13h09m
Dec.	+11°33'
Mag.	+14



First Quarter

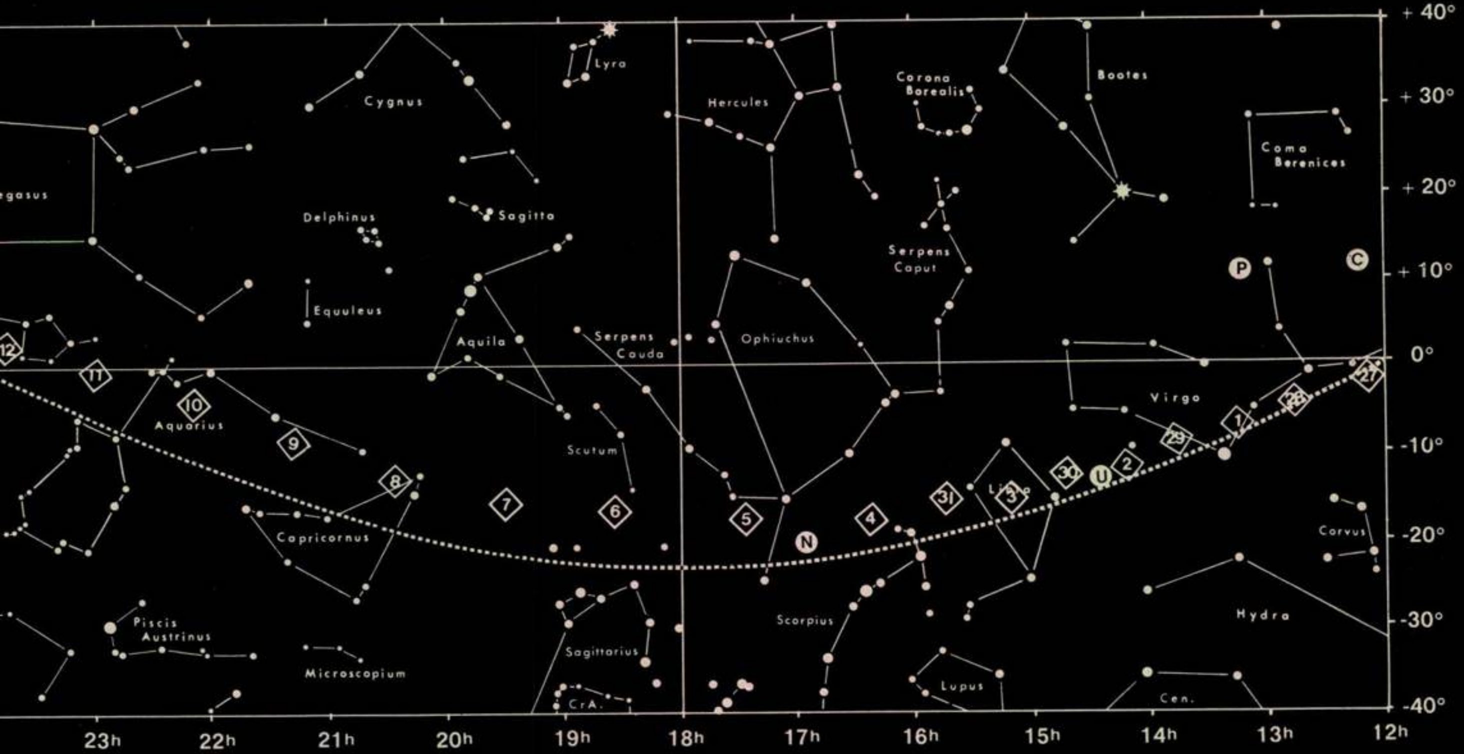
May 25

Full Moon

May 3

Last Quarter

May 10


+40°
+30°
+20°
+10°
0°
-10°
-20°
-30°
-40°
egasus
Cygnus
Lyra
Hercules
Corona Borealis
Bootes
Coma Berenices
Delphinus
Sagitta
Serpens Caput
Equuleus
Aquila
Serpens Cauda
Ophiuchus
Virgo
Aquarius
Scutum
Libra
Capricornus
Corvus
Scorpius
Hydra
Piscis Austrinus
Sagittarius
Microscopium
Lupus
CrA.
Cen.
P
C
N
U
12
11
10
9
8
7
6
5
4
31
3
30
2
29
1
28
27
23h
22h
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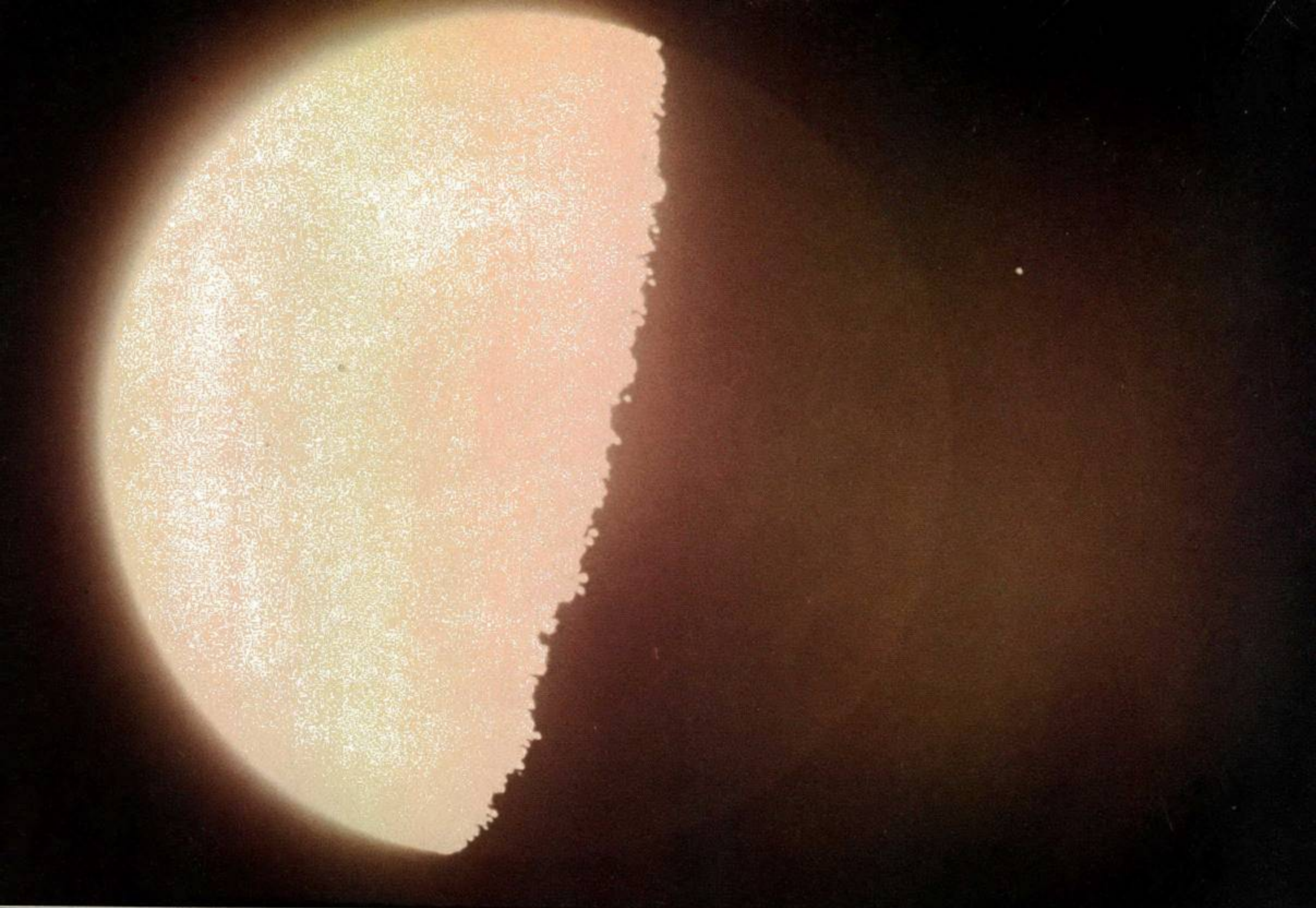
18h
17h
16h
15h
14h
13h
12h

measurement of the object's brightness. (The minus magnitudes indicate very bright planets.) The diamonds with numbers within them indicate the position of the moon for each day of the month; the numbers correspond to the dates. Positions of the planets are for the 15th of the month except for Mercury and Venus which are shown on both the 1st and 15th. Certain areas of this map and the Star Dome chart overlap each month.



Bright Asteroids at Opposition in May

		Location at Opposition			
Asteroid	Opposition Date	R.A.	Dec.	Magnitude	Constellation
9 Metis	May 3	14^h36^m	-10°53'	9.7	Libra
19 Fortuna	May 7	14^h55^m	-16°06'	11.1	Libra
30 Urania	May 8	14^h57^m	-20°21'	11.2	Libra
324 Bamberga	May 12	15^h14^m	-34°53'	11.7	Serpens Caput
3 Juno	May 17	15^h31^m	-02°06'	10.3	Centaurus
29 Amphitrite	May 28	16^h15^m	-30°33'	9.9	Scorpius
18 Melpomene	May 31	16^h27^m	-04°59'	10.2	Ophiuchus

the eastern sky for about an hour before sunrise during May. Its distance from Earth decreases this month from 189 million miles (303 million kilometers) to 179 million (288 million). On May 14 — the date of Venus' occultation by the moon — Mars can be found two to four degrees (depending on your latitude) south of the moon.

Saturn

The ringed planet can still be easily found high in the evening sky. Its magnitude is +0.6 — by far the brightest object in the dim constellation Cancer — and it sets about midnight. Its distance from Earth increases from 847 million miles (1,361 million kilometers) at the beginning of May to 891 million (1,443 million) by month's end.

Jupiter

Rapidly approaching conjunction with the sun on June 4, Jupiter is swallowed up in the sun's light by the end of May. Its distance from Earth is 553 million miles (889 million kilometers) at the beginning of May, increasing to 565 million (908 million) by month's end. Observation of the planet grows progressively more difficult; on the 20th, it can be found five degrees north of the first magnitude star Aldebaran in Taurus, very low above the western horizon just after sunset.

Mercury

On May 27, Mercury will be at greatest western elongation, situated 25 degrees west of the sun and visible in the morning sky. This, however, will be an unfavorable elongation, as Mercury will be located only about 10 degrees above the eastern horizon at sunrise. Its magnitude on the 27th is +0.8.

Top: Uranus emerges from occultation by the moon in this photograph taken at 3:50 a.m. CST on Feb. 10. An eight inch Schmidt-Cassegrain at f/10 was used; Fujichrome 100 film was exposed for three seconds. Photograph by Sheldon Faworski. Left: This photo of M-42 was obtained with a "newly completed" 14 inch reflector at f/5.6; exposure time was nine minutes. This is a print made from a color negative obtained by developing Fujichrome R-100 film in Kodak's C-22 color developer. Photograph by Stan Lovingfoss. Center right: The moon and Jupiter passed within 1/4 degree of each other on Jan. 28. This photo, taken in Melbourne, Australia, is a one second exposure made with a four inch reflector, using eyepiece projection. Photograph by E. Gainsford. Bottom: Eyepiece projection was also used for this four second exposure (at left) on Kodachrome 64 of Jupiter, taken Dec. 20, 1976. Photograph by John Mough. This picture of Saturn (right) is a three second exposure on Ektachrome 160, made with a 14 inch Schmidt-Cassegrain at f/80. Photograph by James Rouse.

Uranus, Neptune, Pluto

The three dimmest planets are all in excellent positions for observation. Check last month's Gazer's Gazette for details and observing hints.

Asteroids

Several relatively bright asteroids reach opposition during May; three of these will be located in the constellation Libra. Asteroid 9 Metis, in opposition on the 3rd, can be found about five degrees west of Xi 1 and 2 Librae; 19 Fortuna will be located halfway between Nu and Alpha Librae on the 7th, and 30 Urania is three degrees southwest of Iota Librae on the 8th.

On May 17, asteroid 3 Juno (one of the well-known "big four") reaches opposition near the southern border of Serpens Caput, about one degree due south of the star 11 Serpentis. 18 Melpomene will be at opposition on the last day of the month in Ophiuchus, about 2-1/2 degrees east of Epsilon Ophiuchi.

Two other asteroids reach opposition much farther south: 324 Bamberga, on May 12 in Centaurus, about 4-1/2 degrees west of Psi 1 and 2 Centauri, and on the 28th, 29 Amphitrite in Scorpius, about two degrees south of the fifth magnitude star d Scorpii.

Check the table on this page for these asteroids' exact positions and magnitudes. Photos of any or all can be submitted for possible publication in ASTRONOMY. If you're observing visually, be sure to check the surrounding fields for a few days before and after opposition for positive identification of the asteroid.

Meteors

The light of the just-past-full moon will effectively blot out all but the brightest members of the Eta Aquarid meteor shower, which peaks on May 5. The Eta Aquarids are fairly rapid meteors, and a normal peak rate is about 20 meteors per hour. The shower is named for the star Eta Aquarii, located near its radiant point.

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Donald J. Smith Shadeyside, Ohio

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Norman J. Boisclair Rensselaer, New York

I appreciate the fast shipment of the 20mm Research-Grade Erfle, which was in my hands 4 days after I mailed the order! I would also like to say that the eyepiece is the finest I have ever used, borrowed or seen, and I have seen many in the 15 years I have been an amateur. In the future I intend to convert my battery of eyepieces to Meade Research-Grade orthoscopics, the sooner the better.

Jim Schultz Lyons, Colorado

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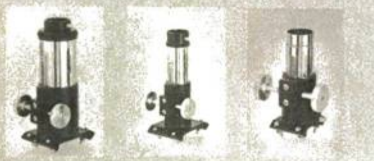

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Research-Grade Orthoscopic Eyepieces (1¼" O.D.) - Multi-coated, 4-element, parfocal. The finest astronomical eyepieces obtainable. *See Item #4.*

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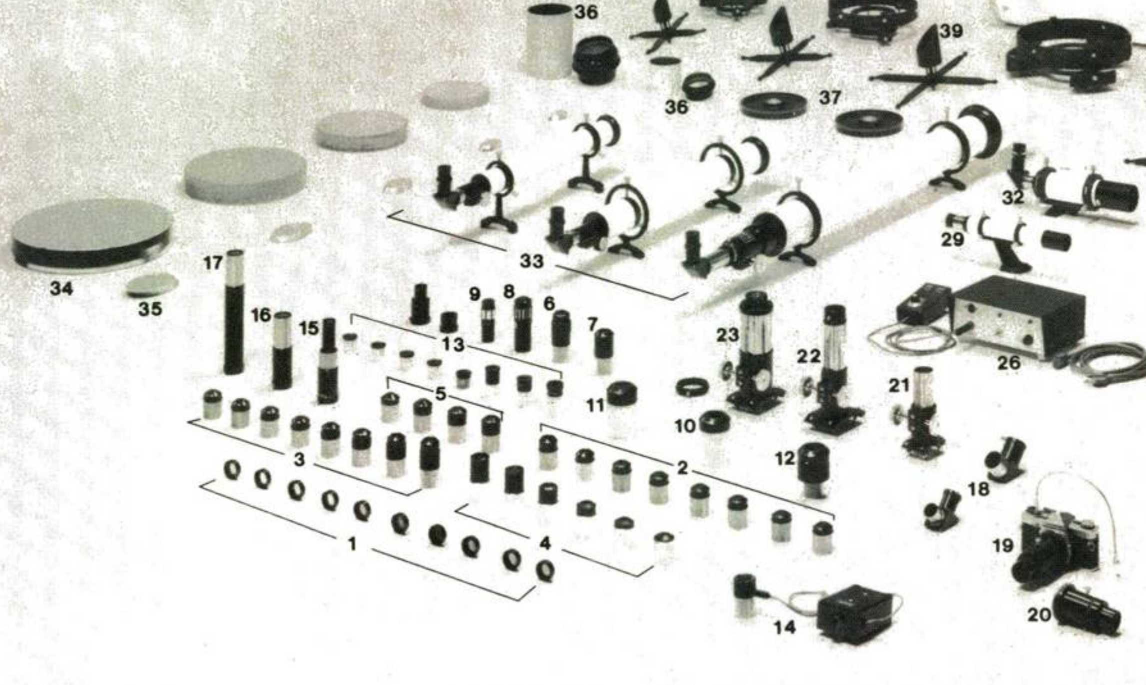

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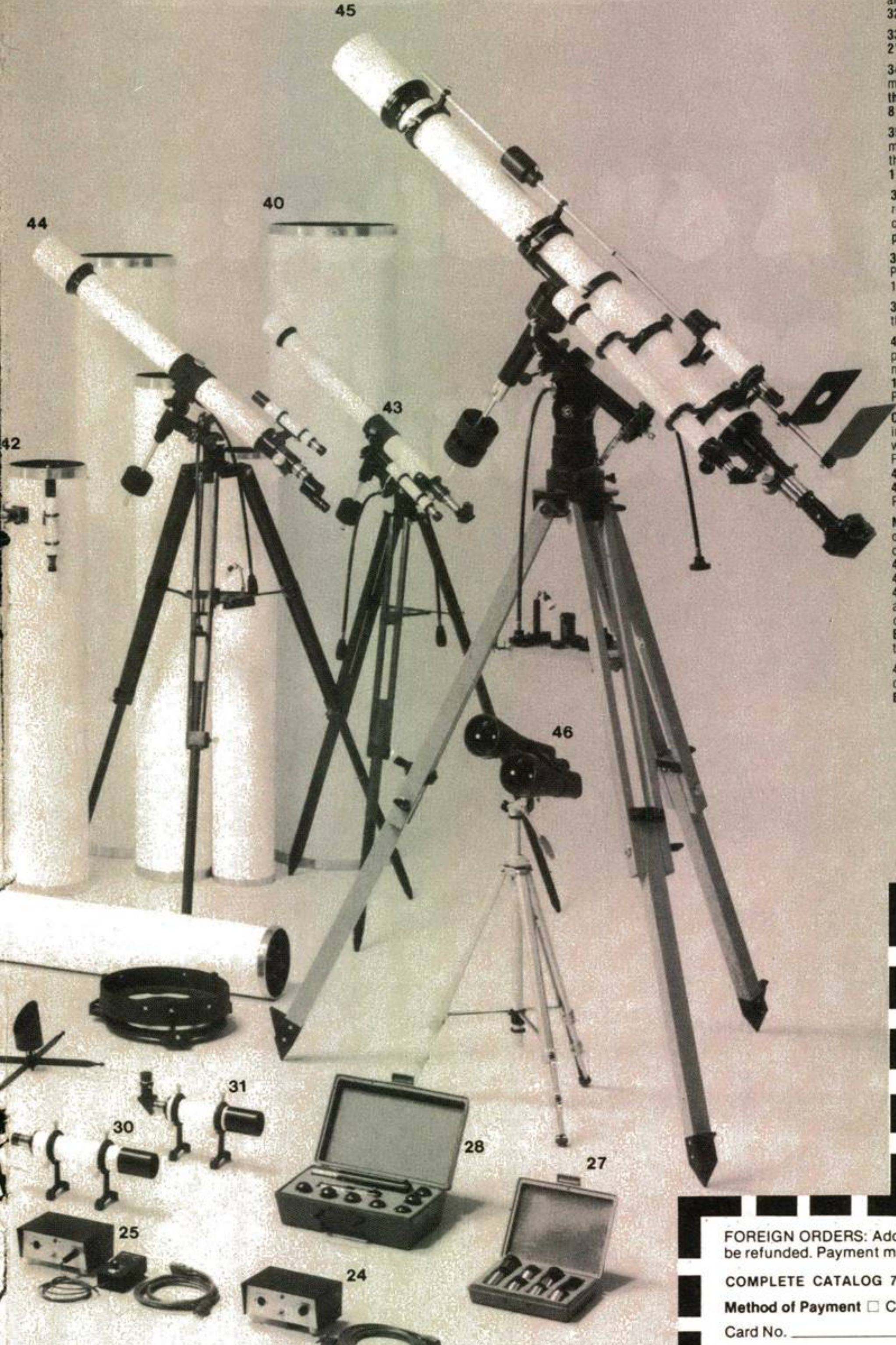

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38, 39 - MIRROR CELLS AND SPIDERS/DIAGONAL HOLDERS are available to fit the tubing below. Phone, or request catalog, for details.

40 - FIBERLITE TELESCOPE TUBES - 20% more rigid, yet 40% lighter, than pure fiberglass, with low thermal conductivity. Polished end rings available at nominal cost. Partial price list: **7'' I.D. x 50''...$36.00 - 9-1/4'' I.D. x 60''...$49.50 12-3/8'' I.D. x 62''...$68.00 - 12-3/8'' I.D. x 72''...$76.00**
Packing charge on tubes...**$4.00.**

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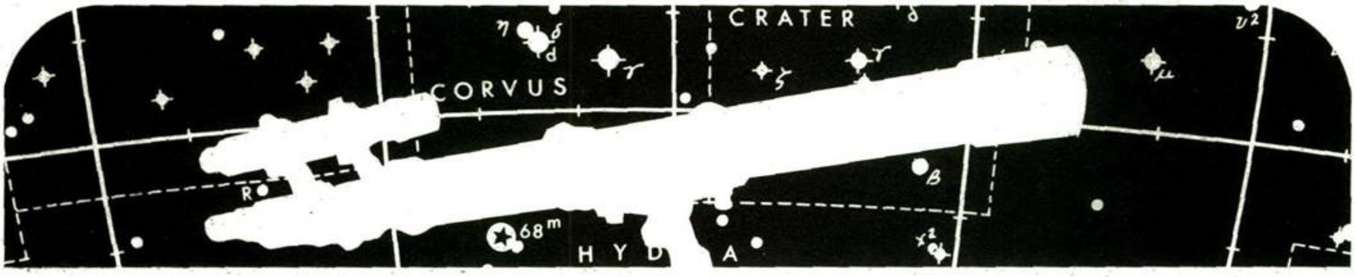


Building A 6" Reflector
Part 2: Figuring the Mirror

by
Alan P. Witzgall

Last month in Part 1, we described the procedures for grinding and polishing a six inch mirror of approximately 48 inches focal length (f/8). This month, we'll complete the job of transforming our mirror's surface into an accurate sphere, and then into a precision "parabolic" astronomical mirror!

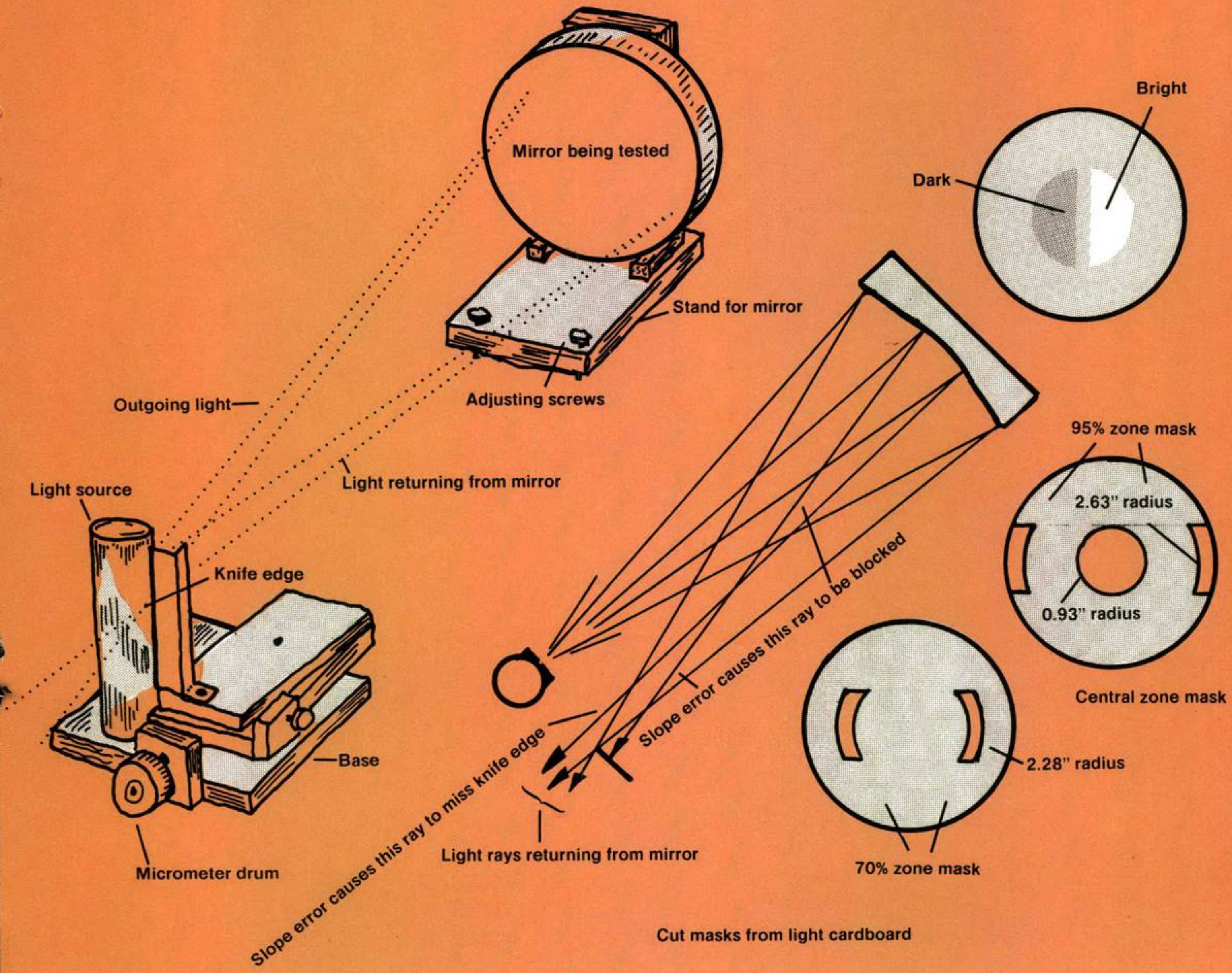
Some questions are in order here. You may ask, "Why not leave the mirror as is? After all, I imaged the sun to a sharp focus on a white card when I measured the mirror's focal length." If you had a filter and an eyepiece at that "sharp" focus, you'd see that the solar disk would have a blurred and washed-out appearance. This effect is due to a defect inherent in all spherical opticals, called *spherical aberration*. In other words, the light from the center of the mirror focuses slightly closer to the eyepiece than that light returning from the mirror's edge when you use the mirror to image a distant star.

To correct for this, you need to "deepen" the central area of the mirror by several millionths of an inch, to bring light from all over the surface of the mirror to the same focus. The proper centrally deepened sphere — if you work out its exact shape — turns out to be a *paraboloid*, which is a two-dimensional parabola spun on its axis to make a three-dimensional cup shape.

What then is the best way to proceed in forming the paraboloidal surface? Assuming you have completed polishing, your mirror is probably fairly close to having a spherical surface. Continue working on the mirror, using a series of special polishing strokes, until you obtain a nearly perfect sphere. (We'll tell you later how you can measure the shape of the mirror.) Then, using another set of special strokes, you'll convert the sphere into a paraboloid in about 10 minutes' work! Of course, it may not work perfectly the first time; all you'll have to do is apply more special polishing strokes (figuring), or in some cases, continue working until you've got a sphere again; then try again to parabolize. As you work, you'll be learning how to control the mirror surface, so that by the third or fourth try, you can (realistically) expect to finish your precision optical surface.

How do you deepen the middle of the mirror?

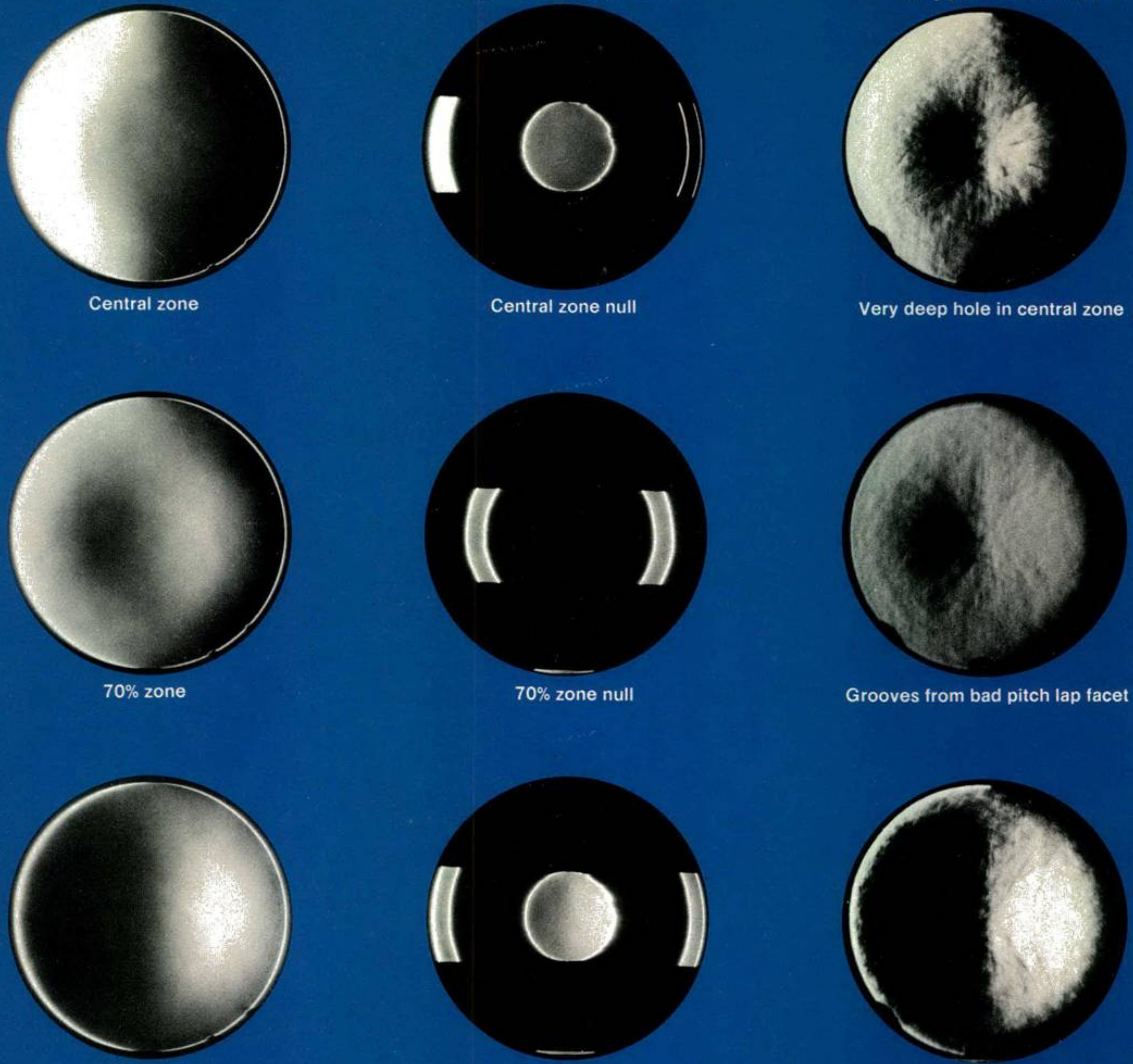
Testing Your Mirror With Light


Mirror being tested
Stand for mirror
Adjusting screws
Outgoing light
Light returning from mirror
Light source
Knife edge
Base
Micrometer drum
Slope error causes this ray to miss knife edge
Slope error causes this ray to be blocked
Light rays returning from mirror
Bright
Dark
95% zone mask
2.63" radius
0.93" radius
Central zone mask
2.28" radius
70% zone mask
Cut masks from light cardboard

The pieces of equipment used for measuring the shape of your mirror are really quite simple: a device called a Foucault tester which consists of a light source and a moveable "knife edge", a stand for your mirror, and several masks cut from cardboard to allow you to make measurements on selected areas of the mirror. The tester is a simple device that you can build yourself if you're at all handy with tools; otherwise, they are available from firms that sell telescope making supplies.

By extending the length of your polishing stroke to as much as 1/2 the mirror's diameter for working periods of up to five minutes at a time and by using very slow strokes (two to three seconds for each back-and-forth sequence) in a 1/3 "W" stroke — most of the "W" should be concentrated over the center of the lap — you'll find you can deepen the mirror smoothly and effectively.

But before you can think about making corrections to the mirror surface, you'll need to measure its shape. Since you know the corrections are very tiny (millionths of an inch), there is no mechanical way to determine the mirror curve. The best way is to use a beam of light. Imagine that you had a very clever machine that shone a beam of light out to every part of the mirror's surface. The mirror, of course, will reflect some of the light back (even before it's been aluminized), so the light will come back together again to form an image of the light from your machine. Suppose now that you cut the returning beam of light with a straight edge in order that any light not returning to form a perfect image is blocked by the straight edge. Now imagine putting your eye behind this machine and looking at the mirror. If there are any "defects", the light from them won't reach your eye but will be blocked by the



The Foucault Test: How A Mirror Looks

Good paraboloid

Testing with zone masks

Poorly parabolized mirror

Central zone

Central zone null

Very deep hole in central zone

70% zone

70% zone null

Grooves from bad pitch lap facet

95% zone

95% zone null

Surface is not "smooth"

Left and center are photographs of a six inch f/8 mirror that gives fine images of the moon, stars and planets. The poor mirror at right was refigured and ultimately became a mirror just as good as the one at right — so don't give up!

edge, and the defects will show up as dark patches. Well, such a wonderful machine does exist! It's called a Foucault tester (named after Leon Foucault, the Frenchman who devised this method of testing telescope mirrors).

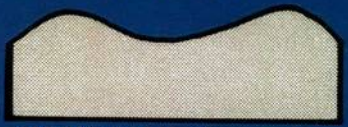
Some of the companies that sell mirror making supplies also sell Foucault testers (sometimes called mirror-testers). University Optics sells an inexpensive do-it-yourself kit. If you are good with tools, you could build one yourself, based on the drawing on page 43. In any case, the tester lets you work toward a definite goal as you figure your mirror, testing what you've done with each successive polishing session.

Let's now examine what we could expect to see with mirrors having different surface shapes, and what the desirable paraboloidal shape would look like.

You've finished polishing the mirror to a perfect clear glass surface everywhere. If everything has gone well, your mirror may have come out a perfect sphere all by itself. Since the sphere is very easy to test, let's see how one would look. In order to form an image on the "knife edge" of the tester, you will have to place the mirror at twice its focal length from the tester, and then align the mirror on its test stand until the returning image falls on the knife edge. Without dragging out a mathematical proof for it, you can see that the tester will lie near the mirror's radius of curvature; thus, each outgoing ray and returning ray is (very nearly) a radius of the sphere. All the rays, therefore, will form an image of

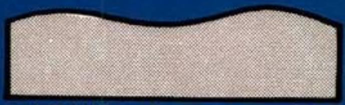
Correcting Defects in Parabolizing

Crests too high



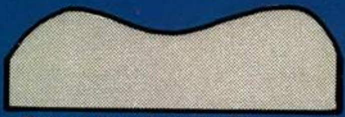
1/6 "W" stroke with pressure

Crests too low



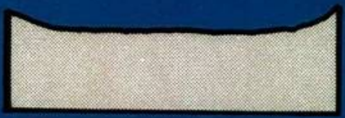
1/2 "W" stroke; test every 5 or 10 minutes

Edge turned down



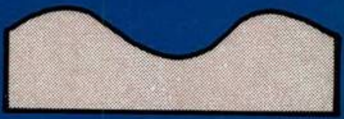
Return to sphere and try again; watch where you place your hands around the edges of the mirror!

Edge turned up



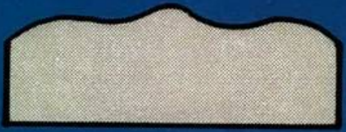
1/3 center-over-center stroke, with moderate pressure

Central hole



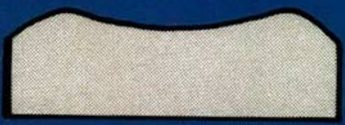
Short, rapid, centered strokes; cold press often

Central hill



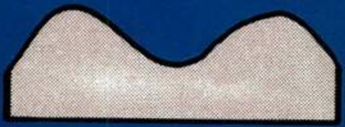
Cold press 1 hour; return to 1/3 "W" stroke; test after 30 minutes

Flat center



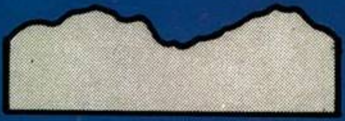
Cold press overnight; 1/2 "W" stroke for 30 minutes and test

Turned edge, central hole and crests too high at same time (hyperbolic)



Use centered, short strokes, with pressure to return to sphere

Surface irregular and bumpy



Slow down your stroke speed

the tester's light source by meeting at the same point. If you cut the image with the knife edge, all the rays will be cut at once, and the mirror will darken uniformly all over. If all went perfectly during polishing (though it seldom does), you'll see the mirror darken uniformly when tested. (See the illustration on page 43 if you're not sure of the fine points.)

Relative to a sphere, a paraboloid is deeper in the center, so in effect the middle of a paraboloid has a shorter focal length than the edges when you use it to image the tester light source to the knife edge. Thus if you test a paraboloid, the edge will darken uniformly, while the center rays will cross each other and diverge again before reaching the knife edge. They will *not* be cut off together, and a recognizable pattern of dark and light shadings will appear on the surface of the mirror.

Far better than simply recognizing the pattern, however, you can measure the focal length (or the radius) of several zones on the mirror and compare them to calculated values. If they match, you'll be assured that your mirror is good. The mirror tester — as you can see from the picture on page 43 — has a measuring screw that moves the knife edge back and forth. By measuring what position causes each zone of the mirror to act like a sphere, you can survey the mirror surface accurately to a few millionths of an inch from eight feet away. That's really quite a feat!

The formula for the determination of these distance changes is: $p = \frac{r^2}{R}$, where "p" is the change

Zonal Shifts for 6" Mirror

Focal Length of Mirror		Middle Zone* Effective Radius = 2.08"			Outer Zone* Effective Radius = 2.79"		
	f/ Number of Mirror	Minimum Acceptable Value	Best Value	Maximum Acceptable Value	Minimum Acceptable Value	Best Value	Maximum Acceptable Value
40		0.040	0.048	0.065	0.069	0.091	0.115
42	f/7	0.037	0.046	0.065	0.062	0.087	0.110
44		0.034	0.043	0.065	0.056	0.083	0.108
46		0.030	0.042	0.065	0.050	0.079	0.106
48	**f/8**	**0.025**	**0.040**	**0.065**	**0.045**	**0.076**	**0.105**
50		0.023	0.038	0.064	0.040	0.073	0.103
52		0.020	0.037	0.063	0.035	0.070	0.102
54	f/9	0.017	0.035	0.062	0.030	0.067	0.100
60	f/10	0.100	0.032	0.062	0.020	0.061	0.098
66	f/11	0.005	0.029	0.061	0.015	0.055	0.096
72	f/12	0.000	0.027	0.060	0.000	0.051	0.095

NOTE: In addition to being within these values, the surface must appear smooth and continuous, without rings or zones.

*Figures valid for an inside zone with an effective radius of .71".

in inches from the center of the mirror as zero point, "r" is the radius of the tested zone and "R" is the radius (twice the focal length) of the mirror. The formula is similar to the one used to determine the sagitta of the mirror. Since we're measuring the depth of field of the returning light, and not the physical depth of the mirror's curve, we have dropped the "2" from the $r^2/2R$ formula. You can find the completed calculation on this page.

In order to consider each zone by itself, it helps to cover the rest of the mirror. From stiff cardboard (file folder cardboard is excellent), cut a mask six inches in diameter, with a .9 inch hole in its center. Try to keep the edge of the central hole sharp and clean (an X-acto knife is good for this purpose).

First, just look at the mirror without the mask in place. Shift the knife back and forth and get a feel for the "shape" of the mirror. Then place the newly completed mask in front of the mirror as it rests in its testing stand. Using the knife edge, find the point, by moving the knife back and forth from the mirror, where the center of the mirror under test just grays out in one action — no leading edge of the knife seen, only light one moment, grayed out the next. Write down the measurement for this point; we will use it as our central area (zero) reference. For accuracy, repeat the measurement three times.

Using another mask made from the same stiff cardboard, but this time having two slots cut at the point of 70 percent of the mirror's three inch radius (2.1 inches from the mirror's center), make the slots about 3/8 inch wide, straddling the previously mentioned point. Also make a third mask with two slots at the 95 percent point of the three inch radius; again, these should be 3/8 inch wide.

Without disturbing the test setup, replace the first mask with the second one. Again, try to find the exact point where the mirror visible at the 70 percent zones gray out together instantaneously, and record this distance from the zero point. Then find the point where the 95 percent zones gray out together and record this, too. Do each measurement three times.

Now we are ready to evaluate our mirror so far. From our measurements, we can compare the depth of the curve on the mirror to that which our formula has calculated. First, average each set of three measurements. Then subtract the zero zone reading from the 70 percent zone reading, and subtract the zero zone from the 95 percent zone reading. Now, compare these numbers to the appropriate line in the table.

Note that you have a tolerance range of 1/4 wave. This means that for the error between the theoretical and actual curve not to vary more than 1/4 wavelength of light, your measurement must fall between these numbers. If you find that the 70 percent zone is too "high" compared to the rest of the curve, you can reduce it by using center-over-center strokes, just long enough to let that region of the mirror reach the edge of the lap. Work for 10 minutes, cold press for 5, and then work 10 more minutes. Clean off the mirror, allow it to cool for 15 minutes, and test again. Continue in this way until it (the crest of the "doughnut shadow" —

you have looked at the mirror without the mask, haven't you?) reaches within the tolerances.

If the crests are too shallow, or the edge is turned up, extend the normal parabolizing stroke when you reach the central region of the lap. Do this sparingly for only three to five minutes, as you can turn the edge down if you overdo it. Your only recourse then will be to return to the 1/3 "W" stroke and hence to a sphere — that is, start all over again.

If you come across a too-deep center, a very high 70 percent zone, and a very turned down edge, you have a *hyperbolic* or *overcorrected* mirror. This is easily remedied by merely using a short (1/6 diameter) center-over-center stroke, with moderately heavy pressure at all times. Work the mirror for at least a half hour before retesting. With luck, you may find a paraboloid at the end of the first period.

A central hole can be treated with the same method as that used for the hyperboloid, but use the stroke for 15 minutes before testing. Central hills will also respond to this treatment. If, at any time, you run into trouble beyond the scope of this article, your best standby is the old 1/3 "W" stroke. It can never do anything worse than smooth out the mirror overall.

Keep a notebook of your measurements and the strokes you have used to rectify the flaws in the mirror's surface. Also, before you do a change in the mirror's surface, look at the unmasked mirror; make a drawing of what shape the mirror shadows would look like if the mirror were seen lit from the edge. This will let you see what has happened to your mirror and enable you to better decide your course of action.

Books About Mirror Making

Many books are available with directions for making your own telescope and telescope mirror. We recommend that you consult at least one additional source of information before finishing your mirror. The books listed below represent only a small sampling of those available.

All About Telescopes by Sam Brown; Edmund Scientific Co., Barrington, N.J. (1967) — simple and profusely illustrated; excellent section on figuring for the beginner.

Making Your Own Telescope by Allyn J. Thompson; Sky Publishing Corp., Cambridge, Mass. (1967) — written in 1947; very good instructions for making a high quality telescope mounting.

Standard Handbook for Telescope Making by N.E. Howard; Thomas Crowell Co., N.Y. (1959) — a complete treatment with everything you need to know, including how to build an observatory.

Amateur Telescope Making (3 volumes) edited by Albert Ingalls; Scientific American Inc., N.Y. (1966) — a potpourri covering just about any topic you may need to know about; organization is rather jumbled.

How To Make A Telescope by Jean Texereau; Interscience Publishers, Inc., N.Y. (1959); available in paperback — for the advanced worker or perfectionist; by far the best section on testing mirrors.

Eventually, the curve will fit inside the tolerances. We're especially interested in making that curve smooth and regular all over its surface. When your calculations fall within our requirements and the curve looks smooth to the eye, your mirror can be considered complete.

Now is the time to consider the next step — aluminizing our mirror's surface. This is necessary because uncoated Pyrex glass can reflect only about four percent of the incoming light to a focus; the rest merely passes through and out the back. A coating of a highly reflective metal is, therefore, required to improve this sorry situation.

Of all metals, silver has the highest reflectivity: 93 percent in green light. Its disadvantages are a natural tendency to tarnish in polluted air, and its extreme softness — it can be scratched during cleaning. Aluminum, while not as reflective (85 percent), is able to withstand our atmosphere's pollutants, and will last at least five or more years. Abrasion will not be nearly as troublesome when cleaning is necessary. Your best bet is to invest in an aluminum coating for the mirror. Average costs range from $12 to $14 for a six inch aperture. ASTRONOMY publishes advertisements for a number of companies which provide this vitally necessary service.

To mail it to an aluminizing firm, wrap your mirror in a thick layer of soft tissue, and then in newspaper and tape. Place this package in a strong box padded with crumpled newspaper as a deterrent against breakage. If you can afford the costs, a box made of 1/2 inch thick plywood is the best shipping container. Enclose with the mirror your check (including return postage and insurance), and a label to help the aluminizer identify your mirror for its return to you.

At their plant, your mirror, along with others, will be placed in a steel vacuum chamber. The chamber will be evacuated to about one-billionth normal air pressure. Inside the chamber, tungsten filaments will be electrically heated to a point where small riders of chemically pure aluminum will melt and "wet" them. Then the filaments will be heated to the boiling point of aluminum. In the vacuum, atoms of aluminum will evaporate onto the surface of the glass, where they will deposit as a coating only about 100 molecules thick. For safety's sake, most coating laboratories will then deposit a just-as-thin coating of silica over the aluminum, thus helping protect it against the elements. When you receive your mirror back from the aluminizer, very carefully unwrap it without touching the reflective surface. Use caution until you have placed the mirror safely in its cell. Then install it in your telescope, and turn it toward the skies.

ASTRONOMERS IN SPACE:

PART 2

by
James E. Oberg

During the 1980s, the Space Shuttle will fly weekly routine commuter runs into orbit. A cadre of NASA astronauts will fly and control these missions. But for every career astronaut who regularly flies into space in the 1980s, there will be perhaps 8 to 10 part time astronauts who will make one-time space expeditions to conduct specialized research programs.

These part time astronauts are *payload specialists* — the visiting scientists to outer space. For centuries, scientists have traveled to the South Pacific, to Antarctica, to mountaintops and the depths of oceans. Recently, a small group of Skylab, Apollo and Gemini scientists have traveled into space after many years of training, but the Space Shuttle will soon open wide the road into space for scientists. They will need only a few months specialized flight training — leaving the "flying" to NASA — and will concentrate on projects to take advantage of the limitless research opportunities of the space environment.

We have already seen how a person might be selected to participate in the payload specialist program (see "Astronomers in Space, Part 1," ASTRONOMY, April 1977) for flights in the mid-1980s. We've seen how experiments will be planned, how flight training will be organized, and how astronomers will be enabled to personally fly into space. But what will it *actually feel like* to be that astronomer who is sent into orbit? From the mission plans now prepared, we can be fairly sure what an astronomer will experience during a research trip into space. So "power-up" your imagination, because launch is today!

When you first heard of this program, the tentative launch date was more than two years away. But now the time has arrived. You have dressed in special space coveralls and loaded your briefcase. You will not be leaving today for the office or the university laboratory; you will be leaving for outer space! Your mission will be to operate a telescope making an ultraviolet light survey of the sky — a vital research tool needed by ground based astronomers.

You board the crew bus for the 10 mile drive to the launch pad at Complex 39. Some flights will leave by daylight and others by starlight. Some crews may even have to dash to the bus through a Florida downpour; only very high winds of violent thunderstorms will delay the regular flights into orbit.

Your ship is one of five operational Space Shuttles. While each has a code number and numerous technical identification codes, each also carries a proud name from earlier epochs of exploration; you are flying with *Endeavor.* Endeavor has been dedicated to the kinds of missions for which you have trained — carrying a group of visiting scientists into space to operate the pallet mounted scientific instruments. Other ships will handle satellite launch, repair and retrieval missions, and pressurized modules of medical and engineering Spacelab missions.

As the bus nears the launch pad, you recall that 10 days ago you watched the Constitution lift off on a routine space probe delivery. The next day — its cargo launched into space — Constitution made a routine landing at the airfield near the launch site, as you and your crewmates watched from atop the Vertical Assembly Building. After months of study, planning, and arduous hours of training, it must have been reassuring to see that the Space Shuttle fleet was real. You began to really believe that you yourself would soon ride one of those rocket planes into the sky and beyond into space.

While Endeavor is on its gantry tower, the winged orbiter section is enshrouded in protective equipment. The long fuel tank attached to Endeavor's belly stands high above the gantry tower. The tips of the two solid rocket boosters are barely visible. Compared to the towering Saturn rockets of the Apollo flights, the Space Shuttle at first looks somewhat disappointing.

The flight crew enters the spaceship first, while the payload specialists hold final preflight discussions with their colleagues. Yes, all the film has been loaded into the telescopic cameras. Yes, the new edition of the tech manual has been loaded into your documentation kit. Your backup man managed to pick up the extra 10 rolls of film for your personal camera. Yes, the balky servo-mechanism on the Y-axis of the telescope mounting has been replaced.

Just as in the drills at the Houston Space Center, you stoop down to enter the circular hatch leading into Endeavor's middeck. Four seats on the flight deck (which in a horizontal spacecraft alignment would be "above" the middeck) are already occupied by the commander, copilot, mission specialist, and one payload specialist. The three remaining payload specialists are strapped in on the collapsible flight couches when the ground crew closes the hatch behind them.

Launch is only a half hour away. The main communication channel is heard over a loudspeaker in the middeck, as the astronaut jargon and countdown procede together. As the gantry tower pulls away, you can see through a tiny window in the hatch to your left.

Only one part of the terminal count concerns you. With only minutes to go, the command astronaut briefly asks about your feelings. Are you ready to go? Forget anything? Well, it's too late now, because . . . .

The three liquid fueled Space Shuttle main engines roar to life, powered by 3,000 pounds per second of liquid oxygen and liquid hydrogen. Their combined thrust of 1-1/2 million pounds is not enough to lift the 4-1/2 million pound spaceship off the launch pad, but once full thrust is confirmed, the two strapped-on solid boosters are ignited. They add another 5-1/2 million pounds of thrust, bringing the total to almost as much as that of a Saturn-V. Endeavor lifts off like a high speed elevator. For the spaceship, it is flight number 32, for the commander, it is flight number 18. For you, it is your first time on a rocket!

Within a minute, the thrust has built up to about 1-1/2 Gs (gravity), when suddenly the whole vehicle seems to lurch. From the mission plan books you remember that the solid boosters are changing their burn pattern to avoid overstressing the spacecraft. As you watch the sky turn black out the small window, the thrust resumes its upward climb; within two minutes it is at three times the force of gravity.

With another lurch and a series of disconcerting creaks and clangs, the expended solid boosters are jettisoned. Somewhere else you once read that a small fleet is waiting at sea to recover the rocket stages and tow them back to Cape Canaveral to be refueled. But this thought is forgotten as the thrust slowly builds back up again. Although the rocket power is constant, Endeavor is becoming progressively lighter, burning up its hundreds of tons of propellants.

By now you are really in space and the G forces have again reached their maximum of three times the normal force. A glance out the hatch window gives you a glimpse of the horizon upside down! Endeavor is making its final approach to orbit in a "heads down" attitude! This, too, is normal.

More than 1,000 miles downrange from Cape Canaveral at an altitude of about 60 miles, and only 8-1/2 minutes after liftoff, the flight computers become satisfied with the measured acceleration, velocity and range, and trigger commands to shut off the three main engines. You bounce forward in your seat, held only by the restraining straps, and are introduced to real "zero gravity".

You may think for a moment that you're in orbit, but you aren't yet; Endeavor has shut off its main engines just shy of orbital velocity in order to drop off the giant fuel tank which has powered the main engines. You are on a suborbital trajectory which will dump the tank in the southern Indian Ocean in about a half hour. It will not be recovered.

To avoid the same fate, the orbiter fires up its small Orbital Maneuvering System engines as soon as the tank is sent tumbling off on its short space trip. The rocket acceleration of 1/15 G is like a love tap following the pounding of the main engines. After another minute of firing, Endeavor has been injected into an orbit which will take it about 100 miles above Earth. A half hour later, at this highest point of the orbit, the small engines fire one more time to raise the low point above the atmosphere as well. You are finally in orbit!

During training flights on Earth, you have already experienced brief "free fall" periods. Now in space, it will last for more than a week. Learning to live and work under these conditions has taken space specialists many years to master, and you have been schooled extensively.

The flight deck is now the scene of rapid and precise work by the professional astronauts. Having determined that no emergency landing will be required, they are "reconfiguring" Endeavor for orbital flight. The antennas and the payload bay doors are being unstowed and opened. The computers are digesting the actual flight path and comparing it to the planned one in order to compute any corrections that might be needed later. During all this, you sit and wait and listen.

Within a half hour of reaching orbit, you will begin to feel the first effects of weightlessness on your body. It seems that blood is rushing to your head, and your sinus cavities feel a little blocked. As your body fluids redistribute themselves, look out! Your face will get puffy and your eyes will take on a slightly squinted look. You may feel like taking deep breaths as your chest seems to fill with fluids. Many other payload specialists have reported the illusion of "flying upside down" or "being tilted backwards", or similar effects of the body's frantic signaling to the brain of the changes wrought by weightlessness. You may get a dull headache for a few hours, but it will pass. If you follow the rules, your working capacity should not be impaired at all. Just don't hurry!

Finally, you very gently unstrap yourself and glide over to the hatch window. Unlike the random orientation of equipment in some of the earlier spacecraft, the hardware of the Space Shuttle cabin is set up in a distinctly "up-down" system with floor, walls, and ceiling. Skylab astronauts found that changing one's frame of reference by turning upside down was quite possible but often confusing. On Endeavor you will probably make a habit of keeping your head "up" except for occasional deliberate attempts at zero-G gymnastics.

Nobody could have forecast your reaction to the view of Earth from space. Despite the thousands of photographs, movies and briefings, the effect of actually being there had never been conveyed — until now. Nothing you've ever read could have prepared you for the sight. After your return to Earth, you may find yourself becoming involved in the environmental protection movement.

The copilot and mission specialist help in the stowing of the seats and the unstowing and assembly of the bunks. Half the crew will be going to sleep soon, while the other half activates the scientific equipment, monitors the outgassing of residual contaminants from the payload bay, and handles the inevitable scheduling and equipment anomalies which crop up. The theory behind regular Space Shuttle science sorties is that a higher incidence of equipment failure will be tolerated in exchange for a considerably reduced cost of equipment. It usually turns out that to increase reliability from, say, 95 to 99 percent, equipment costs are increased by a factor of 10. Often, it's cheaper to suffer the failures and fly occasional backup missions rather than to attempt to forestall all failures.

Meals on board Endeavor come from the galley — a 4 x 8 foot closet sized assembly in the middeck. Packages of ready-to-eat food as well as rehydrates are available, with each package individually coded per crewmen and meal.

Since you are on the second shift, it next is time to try to get to sleep. Prior to retiring, you try the famous zero G toilet, where the designers have found a way to replace gravity with air currents. To sleep, you may take a sleeping pill, don earplugs, and then crawl into your berth. Much like the sleeping compartments on old trains on Earth, the berth is a coffin sized frame with a privacy curtain across the front and a sleeping bag tethered to the "bottom" side.

One of the banes of space travel in the 1960s and 1970s was the continuous medical supervision and monitoring of the crewmen. Operational space missions of the 1980s will have foregone much of that complexity, but not entirely. In an attempt to develop health statistics about the new payload specialists, space doctors have developed a series of medical tests for monitoring basic functions. For reasons of pure medical supervision, the heart rates of all new payload specialists are monitored during launch and for a few hours into the flight. But since the flight is not a long one, there is no organized program for physical conditioning or exercise in the flight plan.

After a good sleep, an adequate breakfast, and another demonstration of the cleverness of outer space plumbers, you are ready to get down to work. You review the flight plans for the second day, and go "upstairs" to the flight deck to begin the astronomical work you've spent years preparing for.

The flight deck is laid out like only a spacecraft could be. True, the forward end has the two seats for the pilots, and is crammed with instruments, hand controllers, rudder pedals, computer terminals and display screens — but that is only where the astronauts sit for launch and landing. Once in orbit, they steer the ship from control panels facing aft!

The *aft flight deck*, as it is called, consists of four work stations, but it's unlikely they will be occupied simultaneously. In the middle of the rear wall of the cabin is a window which looks out into the payload bay and, with the bay doors open on top, back past the orbiter's tail. To the left of this window are the docking control instruments used to rendezvous with target satellites, while to the right is the payload handling station for control of the equipment used to load and unload the cargo bay in space. Neither of these functions will be utilized on an astronomy mission like yours, however. The two other work stations are where the scientists will be spending their time.

The *mission station* is on the aft-facing left wall of the cabin, and the *payload station* is on the right wall. Here are the dials and lights for monitoring status of the ship and its payload equipment, and closed circuit television screens for closeup viewing of equipment outside, computer keyboards, and display screens for communication with the equipment. Although the instruments are only 20 to 50 feet away, they will be controlled remotely from these panels.

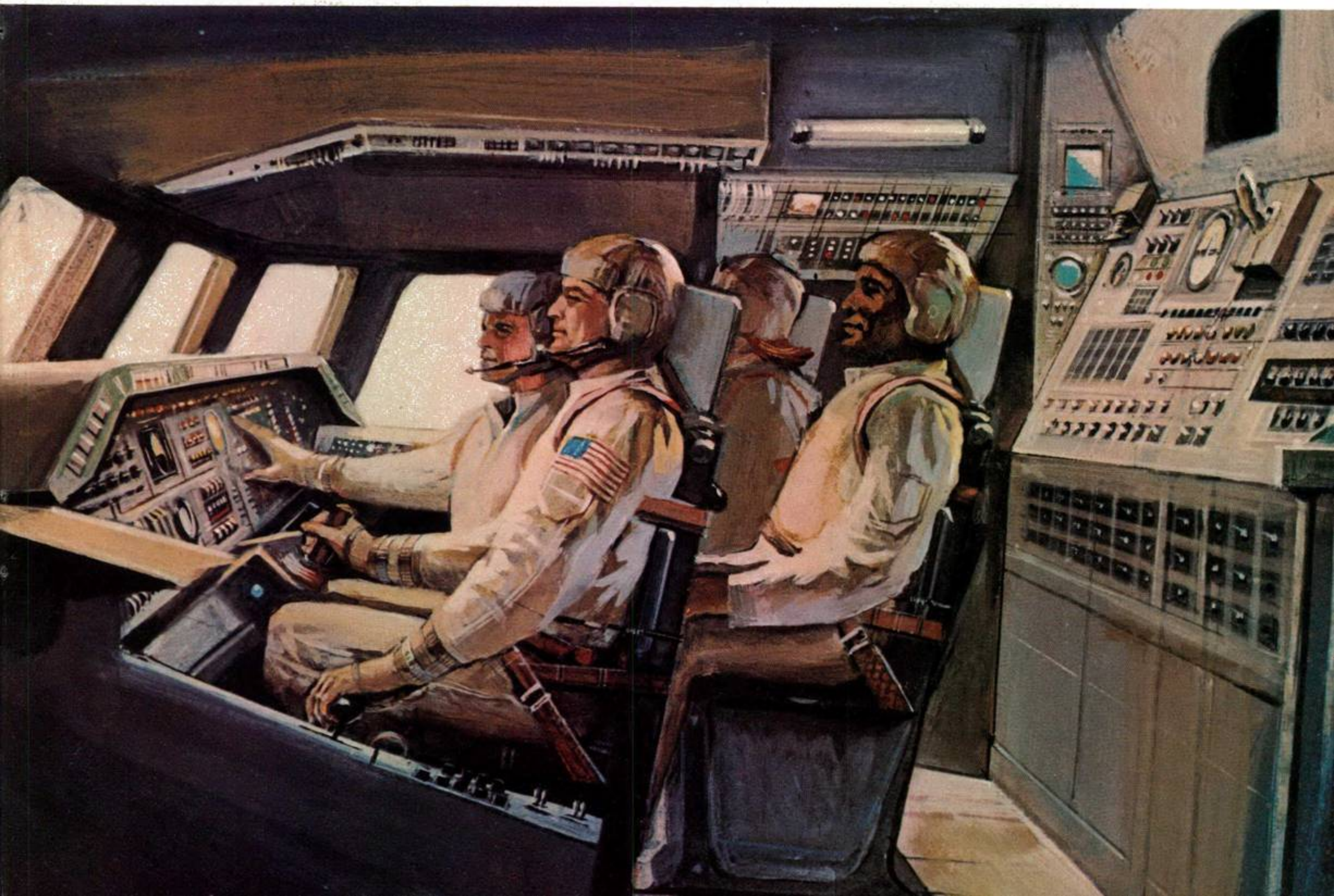
In the event of equipment problems, two crewmen (the mission specialist and the copilot) can don spacesuits and spend up to six hours in space adjusting equipment, attempting to repair it, retrieving it, or hitting it with a hammer. Since it takes hours to prepare for extravehicular activity (EVA), and since the air released when the door is opened takes hours to completely disperse from the payload bay and its delicate instrumentation, EVA is undesirable and thus not a common occurrence on these types of missions.

A typical astronomical mission might involve an ultraviolet light deep sky survey — and in fact, that is your mission. Surveys are very valuable because they often result in unexpected discoveries, and in the case of an ultraviolet survey, it can easily be compared to photographs in visible light. The instrument — a survey camera — has been deployed on a small elevator until it is above the payload bay sides, extending into open space. The flight plan takes into account the mission geometries to avoid glare from viewing within 90 degrees of the sun or 15 degrees of Earth or the moon. Before liftoff, a 43 meter reel of 200mm wide film was loaded into the camera system. You have 200 frames to expose — two on each orbit — for 15 minutes each exposure. The instrument is controlled from an indicator and switch panel, a display screen and keyboard, a camera control panel, and a fine-pointing control.

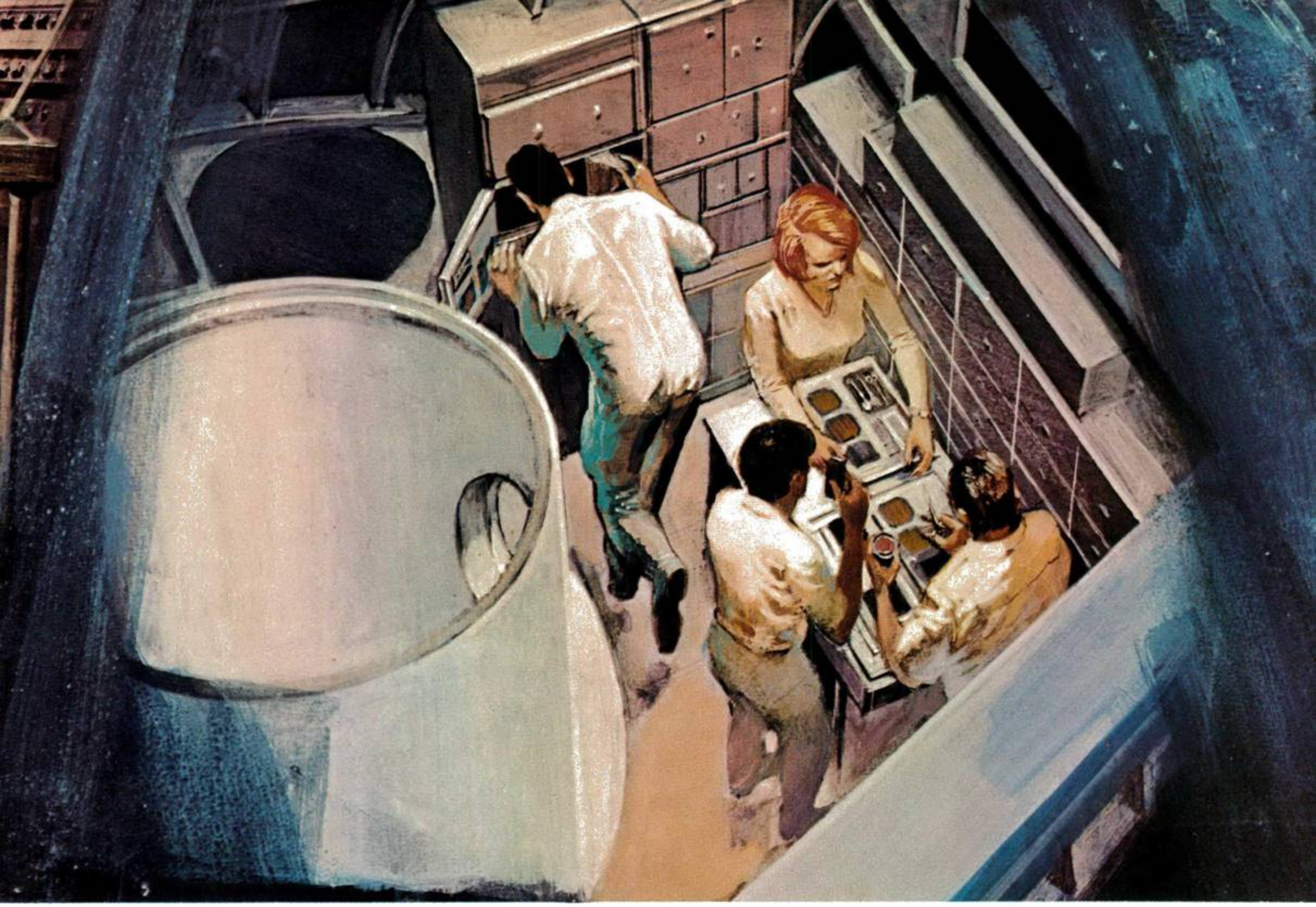
Each exposure covers a 4-1/2 by 4-1/2 degree field of view. Your work cycle runs like this: Setup time, 39 minutes; expose two frames in 30 minutes while the orbiter is in Earth's shadow; then data evaluation for 21 minutes. During the setup time you will have to point the telescope and check equipment (24 minutes, including time for the entire orbiter to move from one setting to another); find your guide stars and take a sighting (one minute); adjust alignment and adjust to desired field (six minutes); calibrate (three minutes), and open the shutter. After two exposures you will close the shutter, advance the film, and evaluate the instrument's performance. You will do this for 12 hours per day, occasionally spelled by another crewman so you can eat a meal. While the work is routine, you are driven by the excitement that each new picture may contain several discoveries.

In this program, even if you are alone in orbit, powerful communications links will tie you to the Payload Operations Control Center (POCC) on Earth. There, other scientists are able and eager to advise you on contingency operations. Unlike early space flights (which were in contact with Earth only intermittently), your mission will make use of two powerful relay satellites in geosynchronous orbit to provide you a constant link with Earth.

The actual scientific experiments which will be



Nearly weightless at the edge of space, Space Shuttle astronauts wait through the coast period after the auxiliary fuel tank is jettisoned. At this point in the flight, astronauts are engaged in communications with the ground about takeoff performance and preparations for the final boost into orbit. The flight crew occupies the front seats; a mission specialist and one payload specialist occupy the rear seats. Three more payload specialist astronauts — the scientific crew — are strapped down in the crew quarters below the flight deck. NASA artwork.



carried out in space in the 1980s can only be estimated now in 1977. Many new applications cannot yet be imagined. The only thing we can be sure of is that the lessons of Skylab and Apollo will be verified: *Having human beings in space to conduct scientific observations and experiments results in much more valuable scientific findings,* especially in those areas where human judgment must be instantly applied.

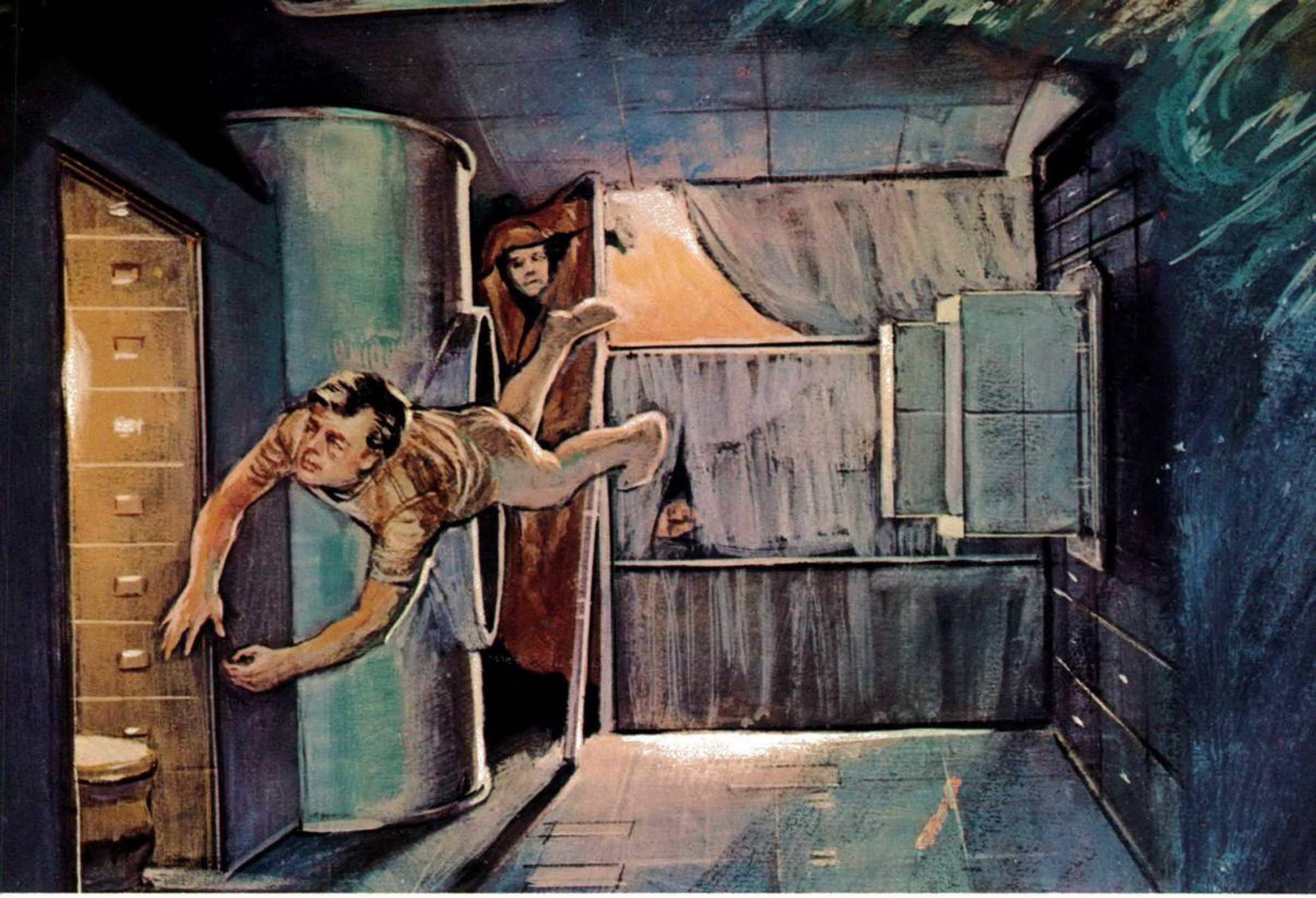
You can also be sure that your mid-1980s astronomy expedition on board Endeavor will be a busy one. There will be no days off on these shorter flights, but during the day you may occasionally find time to look out the window and watch Earth. You may find time for some zero G gymnastics in the cramped quarters of the middeck. And you will bring home new discoveries, new insights, and new plans for future missions.

After two weeks, it will indeed be time to come home. The prelaunch observing plan will have been modified by actual experience; perhaps many items were dropped and others were added. In controlling the experiments — not just your own, but those of many other astronomers also — you had the advice of the mission specialist, your fellow payload specialists, and the scientists and engineers of the POCC back on Earth. But it will have been you — the scientist in orbit — who will have made the operational decisions which determined the success of your part of the mission.

The entire spacecraft must be prepared for reentry now. Instruments in the payload bay are shut down, and the giant bay doors closed and secured. Above all else, your data has been carefully stowed away. In the living area, the bunks have been stowed and the seats assembled for entry. Once more you strap yourself in as the 1/15 G force of the orbital maneuvering engines slowly knock the 150,000 pound satellite out of orbit and put it on a collision course with the edge of the atmosphere. You are headed back toward Earth.

The G forces build slowly this time, and with a difference. Endeavor is doing a giant space "belly flop" into the atmosphere, taking the aerodynamic heating on its underside (the payload bay doors are on top), and as a result is pressing you down against the floor. During launch, you were being pressed back against the aft bulkhead. (Astronauts call the two modes "eyeballs down" and "eyeballs in"; a third mode, "eyeballs out", has never seriously been considered!)

For 15 minutes the forces build to a crushing load. The commander then informs you that the G forces now total about Earth normal (one G), even though you were imagining yourself being crushed to death by 10 or 20 times your normal weight. A



Left: Food preparation will be far more pleasant for Shuttle astronauts than it was for pioneering astronauts. Note that a spoon, fork and scissors are provided with your food. The penalty for weightlessness is that food will be served in plastic bags. Above: Circling above Earth in space, off duty and sleepy from a long day with the astronomical instruments you are responsible for, the mundane intrudes as you float groggily toward the "head". NASA artwork.

week or two in weightlessness can make you forget what weight really is!

During the next two minutes, the really steep deceleration begins, with the flames of atmospheric entry enveloping Endeavor in a sheath of ionized plasma. As the forces reach their maximum of 1-1/2 Gs, you do not feel very comfortable, but remember that early space travelers endured up to six Gs on re-entry. The winged Space Shuttle reduces this load by stretching it out and re-entering the atmosphere more slowly.

Over a 10 minute period, the G forces buffet around the 1-1/2 G value as the air thickens and the wing surfaces begin to grip an aerodynamic medium. Before you realize it, you are no longer in a ballistic spacecraft but in a gliding aircraft, plunging toward the landing strip now only a few miles ahead. Out the window the sky is blue again. You catch sight of the horizon as Endeavor banks for the final approach. Then, moments before touchdown, the nose pulls up to carry out the "final flare" maneuver which cuts the descent rate to a comfortable touchdown speed. With a bump and a screech, Endeavor is on the runway and you are back on Earth. It rolls two miles down the airstrip before coming to a stop.

While the thermal tiles on the outside skin of the spacecraft slowly cool, Endeavor sits at the end of the runway. Ground support equipment hooks up to the vehicle to provide air conditioning and power, while the on board systems are being deactivated. In the presence of unfamiliar gravity, you unstrap yourself a bit weakly and stand up. Your balance mechanisms must once again relearn their reflexes.

Two hours later the hatch is open and a ladder is wheeled up to the doorway. With your flight briefcase stuffed with documents and notes, you leave Endeavor, enter a waiting bus, and are driven to the crew quarters for medical examinations, debriefings, and telephone calls to your family and colleagues. Now you begin the arduous task of evaluating the data and learning what you can about what you wanted to learn about in the first place.

But that process is ordinary science, and scientists have been evaluating data for centuries. What is unique and remarkable is that for a few days you were on a scientific expedition into a new frontier, and you personally looked beyond the literal and figurative horizons of Earth. You were in space. In the 1980s there will be 1,000 like you. ◆

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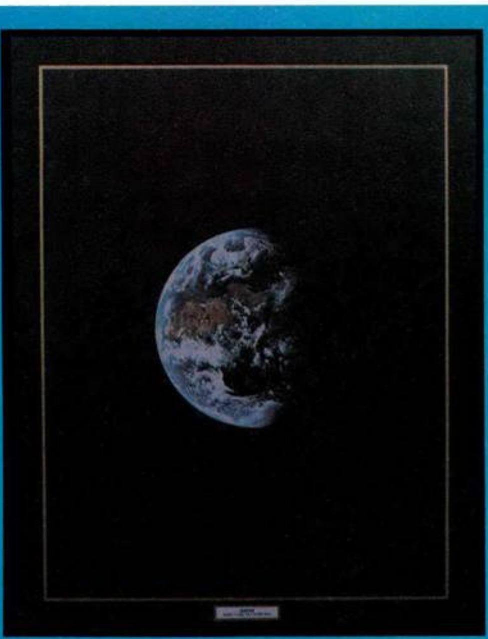
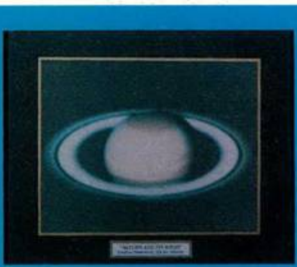


Apollo 11 - Earth

Earth Rise



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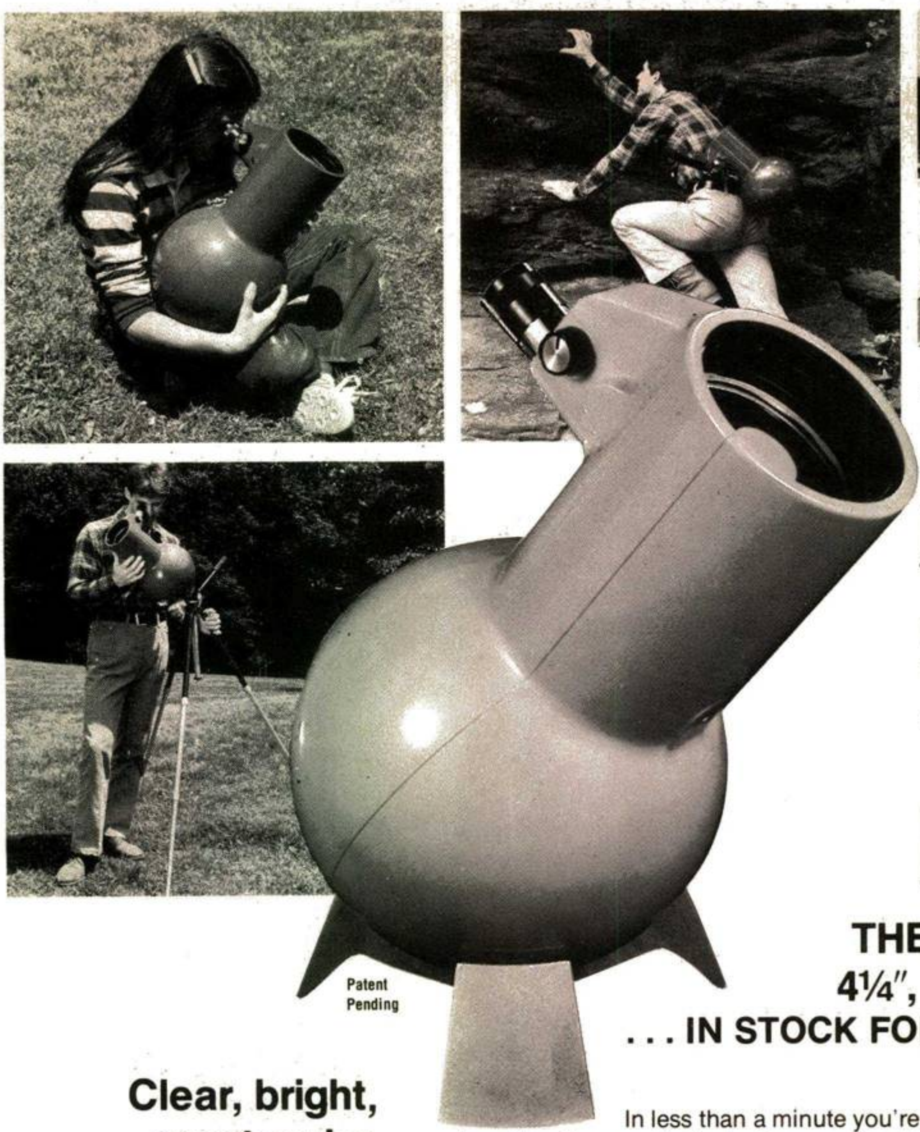

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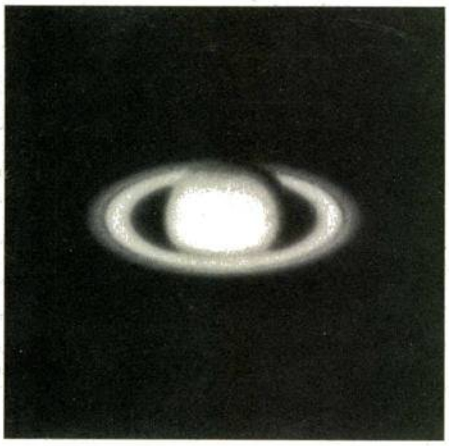
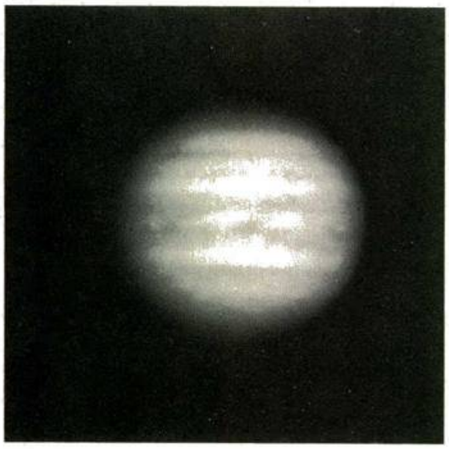
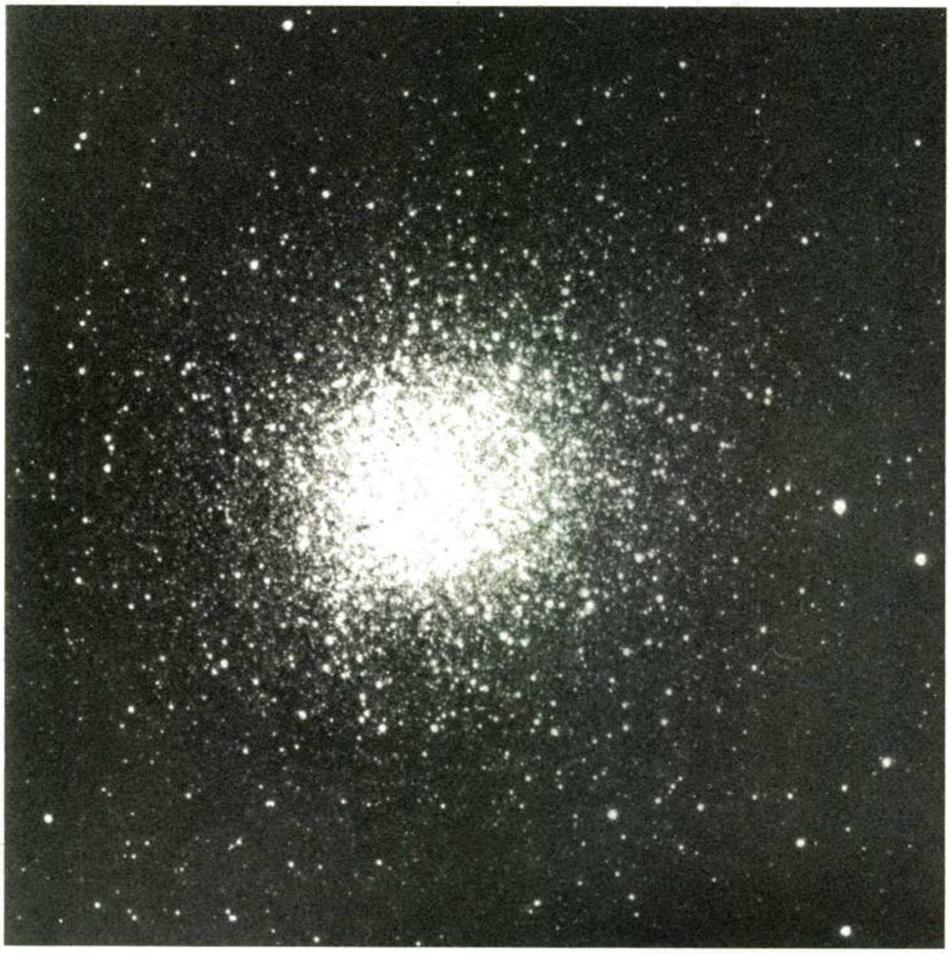


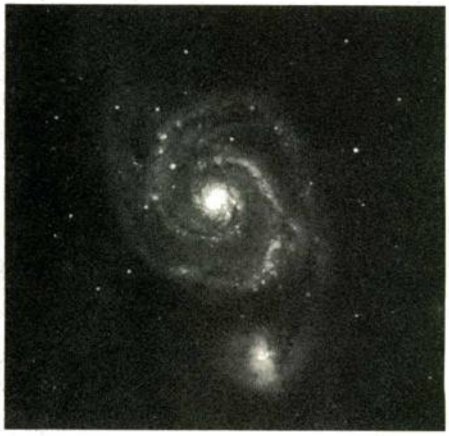
Saturn, 7 secs., SO-410



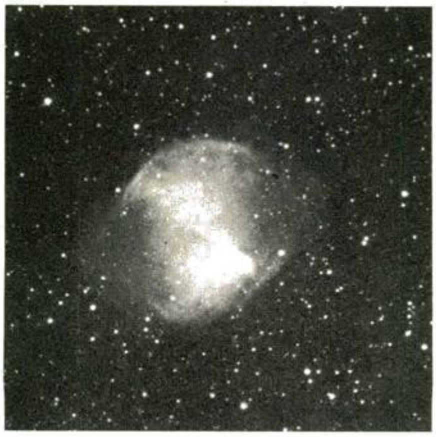
Jupiter, 5 secs., SO-410



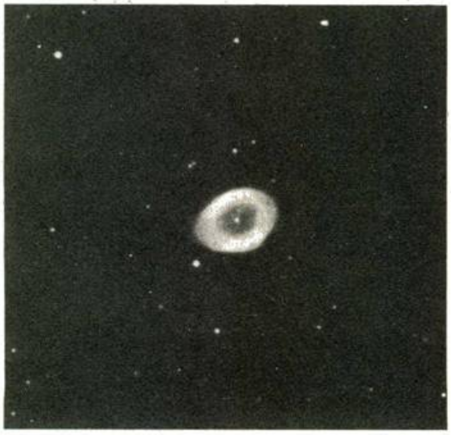
Great Globular Cluster in Hercules, 20 mins., chilled Tri-X



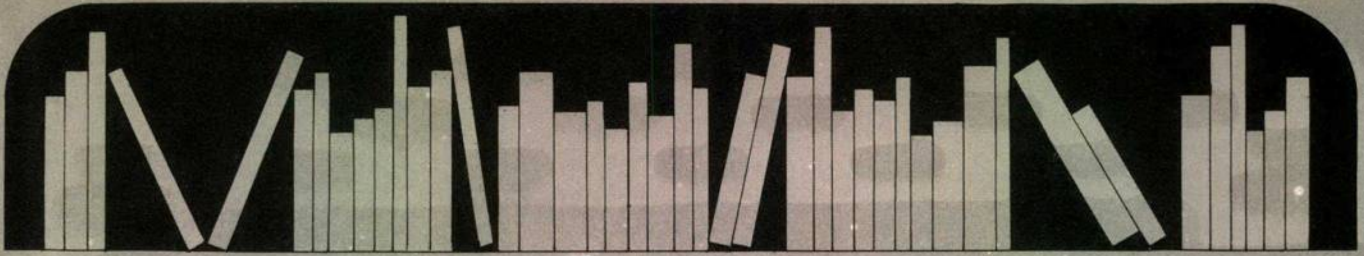
Whirlpool Galaxy, 20 mins., chilled Tri-X



Dumbbell Nebula, 15 mins., chilled Tri-X



Ring Nebula, 20 mins., 103a-F



Glossary of Astronomy and Astrophysics
by JEANNE HOPKINS

169 pages, hardcover, $10.95
University of Chicago Press (1976)

Newcomers to any of the sciences are often bewildered by the proliferation of technical terms that are unique to that science. Astronomy and astrophysics are disciplines that have experienced "information explosions" during the last few decades, and new terms seem to pop up almost daily. Many of these were invented out of sheer desperation; there simply were not existing words in the language that could most precisely convey the intended idea. Both students and professionals are therefore faced with the need for an accurate, timely glossary for reference purposes.

Jeanne Hopkins' **Glossary** fills the bill admirably. Much more thorough than the glossaries found in the backs of most astronomy texts (which are necessarily limited by space), it should prove invaluable to students. Professional astronomers are also likely to find a place for this book on their shelves, as it presents maximum accuracy with minimum verbosity.

In an opening acknowledgement, Hopkins writes: "When I first started copyediting the **Astrophysical Journal** eight years ago, I felt like the girl in **Born Yesterday**. Many of the words either were totally unfamiliar or had a meaning different from any given in standard dictionaries. From sheer necessity I started compiling a list. Whenever I came across a felicitous explanation in a manuscript I was editing, I copied it down . . . . I hope [this compilation] will prove a convenient quick reference for others."

Perhaps because most of Hopkins' definitions are quotes or paraphrases of material originally published by astronomers in the technical journal she copyedits, they are always terse and to the point. Take, for example, the following definition of the Crab nebula:

> "**Crab Nebula (M1, NGC-1952)** A chaotic, expanding mass of gas in Taurus, about 2 kpc distant, the remnant of a Type I supernova whose light reached Earth in 1054. It is an intense radio source (Tau A), and its visible light is strongly polarized. It is also a source of x-rays (2U 0531+22) and gamma rays. Its total mass is about $1M_\odot$, but the total energy radiated by the Crab is 10^{37} - 10^{38} ergs s^{-1}. It is periodically occulted by the moon, and every June its radio spectrum is occulted by the solar corona."

This is a typical example of the definitions in **Glossary**: No words are wasted and information is precise. For a list of technical terms, this is as it should be, and the casual reader who is just becoming acquainted with astronomy's terminology could not do better than to learn it through **Glossary**.

As a whole, the book is quite successful; such errors as do exist are minor. (The Rosette nebula in Monoceros is identified as M-16, whereas it is the Eagle nebula in Serpens that bears this number.)

In his forward, Prof. S. Chandrasekhar (former Managing Editor of the **Astrophysical Journal**) writes, "Miss Hopkins deserves the thanks of all astronomers for her noble efforts in compiling this useful and valuable glossary." The editors of ASTRONOMY agree; we highly recommend this excellent reference book to our readers. *Henry J. Phillips.*

◆

Somebody Else Is On the Moon
by GEORGE LEONARD

196 pages (illus.), hardcover, $8.95
David McKay Co., Inc. (1976)

If you thought you knew the full story of Apollo, says author George Leonard, you fell for our government's cover story. What the astronauts were seeking, and what they found, was evidence about the activities of an extraterrestrial civilization on the moon.

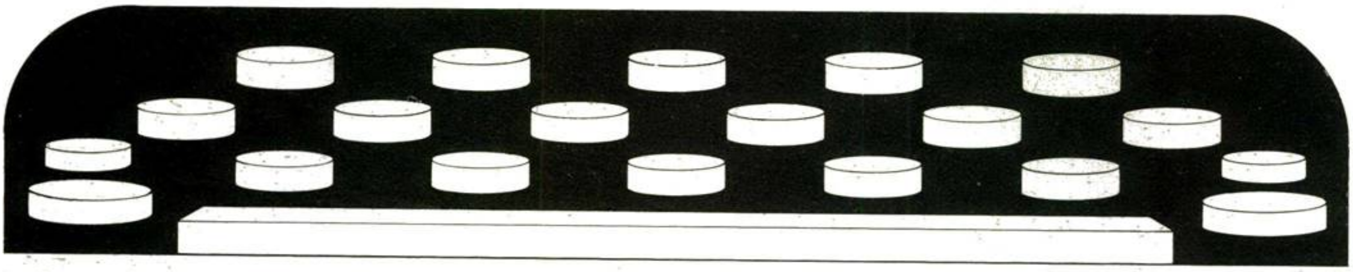
In this incredible book, Leonard tries to prove that "leaked" Apollo data, as well as easily available photos, show that strange artifacts have been spotted on the moon, but that the government is keeping it a secret. To prove this, he presents 35 NASA moon photos and 100 pages of sketches of what he thinks he sees in the shadows and the rocks.

Like the Mars observers of the early 20th century who charted intricate patterns of canals — which were there only in their imaginations — Leonard has stared at the pictures until he can see just what he wants to see, even when no one else can see them too. Worse yet, he bases his entire book on the high contrast, low resolution photos released from the NASA public information offices, and seemingly did not even know that high resolution photos were readily available. When checked, they do not show a single one of his imagined artifacts.

Readers will be hard pressed to imagine why a book based on such demonstrably false premises would even be printed. Those who are willing to give Leonard the benefit of the doubt may even send off to NASA for their own (paid for) copies of the photographs. They will then be even more certain that the book and premise is false, and that the author is a victim of his own imagination.

There is nobody else on the moon. And the only people who will benefit from the purchase of this book will be the publishers and the author. *James E. Oberg.*

◆



IN FOCUS

Ooops!

Here are a few errors that have appeared in recent issues:

February 1977, page 43 — the dates on the diagram of Saturn's orbit are correct; the caption is misleading and could lead you to believe they are wrongly placed.

March 1977, page 11 — the orbits of Phobos and Deimos were incorrectly labeled in the diagram; Phobos' orbit is the inner of the two.

March 1977, page 53 — the credit line should read "Diagram by Patti Heid."

Sir / Living as far south (Florida) and in the city as I do, I never expected to see a good auroral display. On the night of Feb. 26, however, I discovered I was wrong.

At about 7 p.m. I went outside to check the sky; except for a few clouds in the southwest, it was fairly clear. The sun had set 20 minutes earlier and only the moon and planets were bright enough to be visible. I happened to glance toward the northwest and was surprised to see a bright blob of light hanging motionless in midair, about 35 degrees above the horizon.

At 7:05, it was only a bright yellow-green patch of light about 4 x 4 degrees in size. By 7:10 the sky had grown darker and a faint green arc was visible, extending approximately 15 degrees into Cassiopeia. A bright reddish-purple spike was at the southwest edge of the arc. To the left of this spike was a purplish drapery. The entire aurora was about 23 degrees in length.

The aurora was at its maximum size and brightness by 7:20, though it was becoming difficult to observe because of the moon and clouds. By 7:30 the green arc had disappeared completely, leaving only a smaller drapery and spike. The entire aurora had disappeared by 7:40 p.m.

JOEL McREE
Bradenton, Fla.

Sir / In your March 1977 issue, page 53, John Martellaro states that for a pair of binoculars, "the real field is found by dividing the apparent field in degrees by the magnification." This is not true inasmuch as the real field is computed from the following formula: Tangent Half Apparent Field = Magnification x Tangent Half Real Field [see **Binoculars and All-Purpose Telescopes** (1964) by Henry Paul, page 68].

RICHARD LORBER
Canoga Park, Calif.

Mr. Lorber / Right you are; however, the formula given was considered accurate enough for all practical purposes since for "small" angles, the tangent of the angle is very closely proportionate to the angle. Below is a table giving the error involved in using the approximate equation.

Binocular Power	Real Field 8°	6°	4°
5	3-3/4%	— —	— —
7	7%	4-1/4%	— —
8	8-3/4%	5-1/2%	2-1/2%
10	— —	8-1/2%	3-3/4%
12	— —	— —	5-1/2%

Sir / The recent speculation regarding a possible 10th planet ("Pluto", ASTRONOMY, February 1977) was carefully and responsibly guarded. However, to discourage the sort of overdone fantasies that perpetually flood this field, especially when computers or science fiction minds get out of hand, it should be added that an extensive 1973 perturbational analysis has shown that trans-Plutonian planets at likely distances from the sun (about 60 astronomical units) must be unspectacularly modest in mass — more terrestrial than Jovian.

And regarding your concurrent discussion of the problem of Pluto's mass: As one who has long held for a mass of about two or three percent Earth+moon (EM), I would like to point out that the current (explicitly tentative) I.A.U. mass of Pluto (11 percent EM) is based on a 1971 perturbational estimate which employs a rather unorthodox weighting scheme, yielding 11 percent EM ± 2 percent EM. If customary straightforward methods are applied to the very same data (1846-1968 Neptune longitude residuals), the result is 3 percent EM ± 4 percent EM. That is, as long suspected, gravitational analysis tells us nothing about Pluto's mass except that it is negligible. As your writers correctly note, Pluto's various resemblances to Triton are far more informative.

DENNIS RAWLINS
Baltimore, Md.

Sir / I have a 12-1/2 inch reflector which came equipped with the standard 1-1/4 inch rack and pinion focuser. Since I have heard that there are wide-angle viewing advantages with the larger two inch focusers, I am trying to find out whether I would indeed get better wide-angle viewing results with the larger two inch setup on my telescope.

WALTER L. DRAUGHON
Fort Myers, Fla.

Mr. Draughon / You should be able to install a two inch focuser on your telescope with little difficulty. Several of our advertisers offer oversize focusers, either in their ads in ASTRONOMY or in their own catalogs. Choose one that will fit your telescope's tube and has the same height as your present focuser. When you remove the old focuser, make sure to enlarge the opening in the telescope tube enough to allow use of the full two inch diameter of the focuser. Be sure, if you do work on the tube, to cover or remove the optics so they don't get dirty.

Before you put a large focuser on the telescope, however, determine whether you presently are using the full field that can be delivered by a 1-1/4 inch eyepiece. With a 12 inch f/4.5 reflector, you have an eyepiece with a 28mm focal length; its field lens is nearly as large as the eyepiece tube (giving you about 50 power), and the exit pupil of the telescope is about 6mm — about as large as your eye's pupil. You would gain little extra with the larger focuser. However, if your telescope is f/8, the same eyepiece would give about 85 power and a 4mm exit pupil. In this case you could profit from a focuser with a tube large enough to accommodate a 40mm focus eyepiece.

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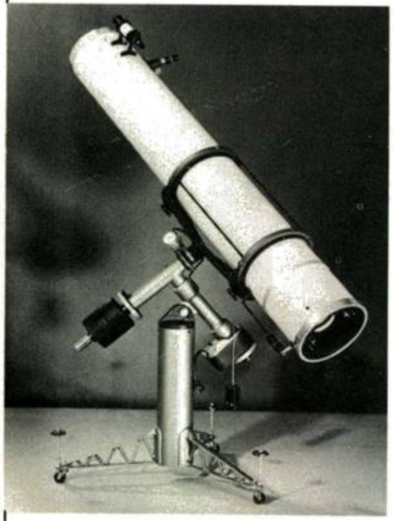

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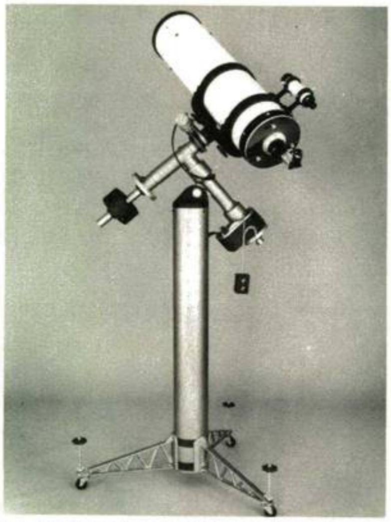

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ASTRO-NEWS

Latest News From the World of Astronomy

Uranus Has Rings

Recent observations indicate the presence of rings or areas of dust or satellites surrounding the planet Uranus, which was previously thought to be circled by only five moons.

The discovery was made on March 10 when Uranus occulted a relatively bright star (SAO 158687). Astronomers in four locations recorded the event; they were: J. Elliot, E. Dunham and D. Mink aboard NASA's Kuiper Airborne Observatory, as it flew over the Indian Ocean; R. Millis, P. Birch and D. Trout at the Perth (Australia) Observatory; J. Churms at the Capetown Observatory, and lastly Bhattacharyya and Kuppuswamy at the Kavalur (India) Observatory.

According to Brian Marsden of the Smithsonian Astrophysical Observatory, the observations strongly suggest that Uranus may be circled by five individual rings. At this point it is not certain whether the rings are composed of solid objects or a rather dense concentration of dust.

Marsden said this is a very complex discovery which needs to be thoroughly analyzed before clear results are established. "I think this is the most significant discovery, in terms of the solar system, since the discovery of Pluto," he said.

Elliot and Millis agree that there are five distinct areas of concentration. The "rings" from the outermost to the innermost have been named Epsilon, Delta, Gamma, Beta, and Alpha. Epsilon is the largest, measuring approximately 60 miles (100km) across. The remaining four areas measure 6 miles (10km) across with the total distance between each area measuring 600 miles (1,000km). The areas lie on a plane with Uranus' equator, with the inner edge at a distance of 26,400 miles (44,000km) and the outer edge at a distance of 30,600 miles (51,000km) from the planet.

There are some differences in the exact figures of each area gathered by the four groups. This may be attributed to variables such as position angle and conditions of viewing. The Capetown group lost most of the last part of the occultation due to the approaching dawn. Of the four groups involved, the one in Kuiper Airborne Observatory seems to have had the best conditions for viewing.

The earliest opportunity for a close-up view of Uranus will be when the Voyager I probe (the renamed Mariner Jupiter-Saturn program) passes the planet in January 1986. Voyager I is scheduled for launch at Cape Canaveral on Aug. 20, and Voyager II will follow on Sept. 1, 1977.

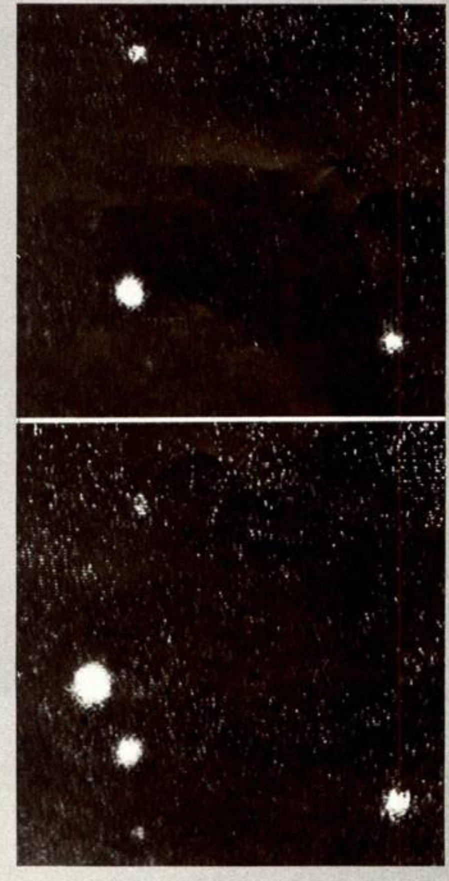
Optical Supernova Remnant Identified in Gum Nebula

The Vela pulsar, the remnant of a supernova explosion, has been found flashing optically at a rate of 11 times per second. It is the second radio pulsar known to have an optical counterpart, and is believed to be the faintest object ever seen in space. The pulsar was found at an average magnitude of 25.6 — 100 million times too faint to be seen with the naked eye. This is believed to make it the faintest object every detected.

The problem in finding the optical pulse after confirming the radio pulse turned out to be the pulsar's extreme faintness. To make the discovery, a combined team of United Kingdom and Australian astronomers turned to the 150 inch Anglo-Australian telescope at Siding Spring. Equipment sent from the Royal Greenwich Observatory (RGO) for data reading and analysis was operated by RGO director F. Graham Smith. Separate equipment — part of NASA's Deep Space Network — was used by Paul Murdin (now stationed at the Anglo-Australian Observatory) to determine the precise pulse rate.

The discovery was aided by Australian radio astronomers who measured the pulsar's position and period precisely. Then the optical astronomers used powerful electronic devices attached to the 150 inch Anglo-Australian reflector to amplify the light from

Vela *continued on page 63*



These television photographs are a good example of what the optical counterpart of a pulsar looks like. The optical remnant of the Crab nebula is shown at minimum and maximum light. Lick Observatory photographs.

Seismic Studies of Solar Pulsations Examine Structure of Sun's Interior

The sun has long been an object of mystery, studied throughout the ages by various cultures. Following is a detailed summary of a talk given by Henry Hill, physics professor at the University of Arizona, during a recent conference of the American Association for the Advancement of Science.

In astrophysics, the importance of the dynamic nature of stars — both in stellar structure itself, and in expanding our knowledge of stellar structure — is being realized as more types of stars are found to pulsate. It now appears that our sun, long considered stable against pulsation, is in fact one of these pulsating stars. The properties of the oscillations observed in the sun are considerably different, however, from the pulsations observed in other variable stars. It is these differences which have made seismic sounding of the sun a powerful new probe of solar structure. In the next few years, seismic sounding will allow a more direct examination of the solar interior than did previously used techniques. It is already proving to be a valuable tool in the examination of global properties of the outer solar atmosphere, where complex surface features have made it difficult in the past.

After an earthquake, our entire planet oscillates with many frequencies; this has allowed terrestrial seismologists to construct a detailed picture of Earth's structure. Most variable stars are observed to oscillate at one, two or three (at most) frequencies, limiting the amount of extractable information. Fortunately for both Earth and the sun, the information available through the study of the oscillations is far greater than simply one or two frequencies. Observations of the sun now show that thousands of oscillatory modes are excited, with periods of near five minutes; at least 20 modes are excited, which have periods varying from five minutes to approximately one hour. There has also been a report of an oscillation with a period near 2 hours 40 minutes.

As study of stellar pulsation progressed over the decades, a philosophy developed in the treatment of pulsations at the outer boundary of the star. Although it was not possible to test the hypotheses, this philosophy became the "proper" description without proof. For the first time, through study of solar oscillations, it has now become possible to test this treatment of the boundary. This accepted treatment appears to be in considerable error, and the consequences of this discovery will be felt in various areas of astrophysics. In particular, this is likely to influence our thinking about the heating of the sun's corona.

Five-minute oscillations of the sun were actually discovered almost two decades ago by Robert Leighton. The understanding of this phenomenon slowly evolved during the intervening years through extensive observational and theoretical work by various groups. Only recently has it become apparent that this five-minute behavior is, in fact, a *global* oscillation of the sun, and not some local surface phenomenon.

By including the five minute oscillations in a program of seismic sounding, it has been possible to show that in certain regions of the solar envelope, the temperature fluctuations associated with these oscillations are much larger than previously thought. This effect was missed in the past because the temperature fluctuations were calculated under the assumption that the system was static, neglecting the effects of oscillations. This discovery is significant: If the temperature perturbations in the oscillating system are indeed as small as previously estimated, then one must reject the current models of the sun's photosphere and/or reject one of the driving mechanisms currently considered important in variable stars.

The immediate impact of the discovery with respect to the temperature fluctuations is to impair an observational technique used in astrophysics for observing temperature changes in an oscillating system. This technique looks for fluctuation in spectral lines where the temperature changes were traditionally thought detectable.

The negative aspect of the reduced temperature sensitivity is more than counterbalanced by the positive results anticipated from seismic sounding of spectral lines. It has been possible to introduce a new observational technique to help ascertain where the spectral lines are formed in the solar atmosphere. The line formation problem is an extremely complex one, and indications are that this new technique should considerably expand our knowledge of the solar atmosphere in ways not previously possible.

The discovery of the solar oscillations has clearly opened up a new diagnostic tool in astrophysics, and current results are only an indication of what future work may yield.

Explosion Caused by Meteor

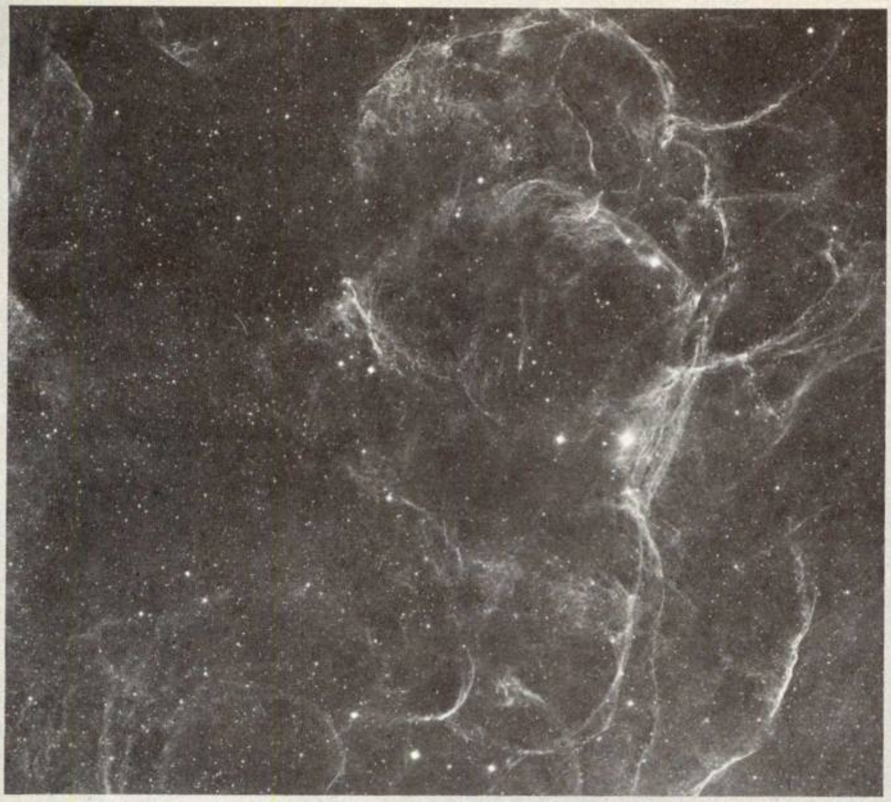
Recent discoveries in the science of meteorics have hinted that the spectacular and mysterious Tunguska explosion in 1908 may have been a larger than usual occurrence of a common celestial event: the atmospheric entry and explosion of carbonaceous chondrite meteors.

The Tunguska explosion took place in Siberia on June 30, 1908. Physical evidence on the ground, together with eyewitness testimony, indicates that an explosion of megaton force occurred high in the air over the remote forest area.

In fact, according to Ronald A. Oriti of the Griffith Observatory in Los Angeles, the Tunguska event is not unique. A similar explosion over Revelstoke in Western Canada in 1965 produced an explosion estimated to have been in the kiloton range — but again, no crater was found. Investigators who reached the scene soon afterward found the snow covered with a dirty black layer of dust. A total of one gram of this black material was recovered for analysis; when the snows melted the dust apparently dissolved and disappeared.

Upon analysis, chemists discovered that the dust was "Type 1 Carbonaceous Chondrite", a fragile and presumably rare type of meteorite. But other evidence from space probes has demonstrated that the vast majority of meteors are caused by this type of material.

The behavior of the Tunguska explosion, therefore, can be easily explained as a large carbonaceous chondrite meteor which left no detectable traces. The first scientific expedition was not able to reach the impact point for more than 20 years, and nothing notable was discovered. Contrary to reports in the "UFO press", these Soviet expeditions did not find any traces of radioactivity.



These photographs show the ultraviolet network of nebulosity associated with the Vela pulsar. The nebula, which covers much of the southern sky, was discovered and named the Gum nebula in 1952 by Colin S. Gum. Steward Observatory photographs.

Vela

continued from page 61

the pulsar area, scanning the resulting signal in search of a periodicity. From a total of eight hours' observing on the nights of Jan. 24 and 26, they found optical flashes at just over 11 times per second — identical to the pulsar's radio period.

The shape of the pulses changes at different wavelengths. The radio pulses show slight signs of splitting into two, whereas gamma ray pulses are definitely double; the optical pulses are now seen to be intermediate in shape.

The history of the Vela pulsar can be traced back through the 6,000 year old texts of the Sumerians, when the area known as Vela was the site of a supernova explosion (see Astro-News, March 1976). Supposedly the supernova was the second one to occur in that area, because a previous one left a nebula covering much of the southern sky. So dim that it wasn't detected until 1952 by Australian astronomer Colin S. Gum, it was subsequently named the Gum nebula. In 1975 gamma rays were detected from the Vela pulsar by the European COS-B satellite which made it a prime candidate for possible optical flashes.

The only other radio pulsar with a known optical counterpart, at the center of the Crab nebula, has a pulse of 30 times per second. It was identified in 1969 at the Steward Observatory of the University of Arizona. One of the participants in that discovery was Englishman Mike Disney, who is now based at the RGO. He urged colleagues to visually search for the Vela pulsar using new telescopes in the southern hemisphere. This was necessary because the Vela pulsar — discovered by Australian radio astronomers in 1969 — is the third fastest pulsar. The fastest spinning pulsars are the youngest and most energetic.

The Crab pulsar, the fastest of all, has been observed at all wavelengths from radio to gamma rays. The second fastest pulsar — flashing 17 times per second — is in a binary system which was detected by R.A. Hulse and J.H. Taylor in 1974. At this time, it does not have an identified optical counterpart.

The Vela pulsar is stronger at radio wavelengths than the Crab pulsar because it is only 1,500 light-years away — 1/4 the Crab's distance. The puzzle is why the Crab pulsar should be over 1,000 times brighter optically — it is easily seen on photographs!

The Anglo-Australian team used their same equipment to examine the light flashes from the Crab pulsar in more detail. They also looked for optical variations from three other fast-spinning pulsars, but without success. This suggests that optical identification of other pulsars is going to be even more difficult.

BRIEFS

- NASA's Lewis Research Center in Cleveland, acting as project manager for the Energy Research and Development Administration, has named Kaman Aerospace Corp. of Bloomfield, Conn., to build the world's largest windmill blade.

  The 15 story, $2 million blade will be constructed primarily of glass fiber, using techniques derived from those applied in building helicopter rotors. It will weigh about 17 tons (19,400kg).

  At 150 feet (45.7 meters), the blade will be more than twice the length of the blades which power the 100 kilowatt wind turbine generator now in use at Lewis Research Center's Plum Brook Station in Sandusky, Ohio.

- NASA has announced the development of large-area, ultrathin silicon solar cells to increase the power-to-weight capability of solar arrays in space. The new cells are thinner than a sheet of newspaper.

  The cells are 40 to 50 microns (about 2/1000 inch) thick — only 1/6 of the 300 micron thickness used in present spacecraft solar arrays. (A micron is 1/25,000 inch.)

  Ultralightweight thin cells will permit develoment of larger solar arrays, producing multikilowatt electrical power for ion propulsion systems for extended space exploration. They will also provide the potential for powering platforms and perhaps remote satellite power stations in the future.

- NASA is literally trying to work the bugs out of aircraft. Engineers and pilots at NASA's Hugh L. Dryden Flight Research Center in Edwards, Calif., are flying a small jet transport to study various materials and methods to prevent crushed insects from sticking to the leading edge of aircraft wings. These impacted insects cancel out the flight efficiency increases made possible with laminar flow.

- NASA sponsored workshops on space battery technology are providing the American taxpayer double dividends for federal funds expended on the research and development of spacecraft power systems.

  The workshops are conducted to help increase the efficiency and lifetime of spacecraft battery systems through exchange of information between users and manufacturers. The program is resulting in better and longer-lived batteries developed in industry for use in heart pacemakers, aircraft, and consumer products such as portable tape recorders, radios and flashlights.

ATS Triples Lifespan

A 10 year old NASA satellite with a design life of three years is still serving the medical emergency communications needs of persons in remote areas of Alaska, as well as relaying educational materials to university students throughout the Pacific area.

When launched on Dec. 7, 1966, the Applications Technology Satellite 1 (ATS-1) heralded a new era in the application of space technology to areas beneficial to man. For the first time, a single spacecraft carried instruments for combined research in communications, meteorology, aerospace engineering and science.

"Although this versatile satellite has already exceeded its design life more than three times, it is still being operated 18 hours a day and potential users are standing in line," according to Richard L. Moore, ATS missions operations manager.

In its sychronous orbit about 22,300 miles (35,680km) above Earth, ATS-1 matches Earth's rotational speed. The 775 pound (352kg) satellite remains stationed over the equator at a point south of Hawaii, until commanded to move. From this perch, ATS-1 views the western and mid-Pacific area, including Alaska and the contiguous United States.

Doctors in Anchorage and Fairbanks are linked via ATS-1 with paramedics or nurses in remote villages and areas where the sick or injured are without modern medical facilities. (Called "Doctor's Call", this vital program is administered by the State of Alaska.) By using the very high frequency (VHF) communications system on the satellite, doctors and paramedics are able to communicate without the interference of fade-out or static, common with standard high frequency communications normally used in remote areas.

Careful programming of the satellite's time permits other useage. One current educational program is called PEACESAT – Pan-Pacific Education and Communications Experiment by Satellite. This international experiment, initiated in 1971 by the University of Hawaii, tests new methods of operation in satellite communications for education, health and community services. It involves the educational institutions of 12 nations in the Pan-Pacific area, ranging from Hawaii south to New Zealand and westward to New Guinea.

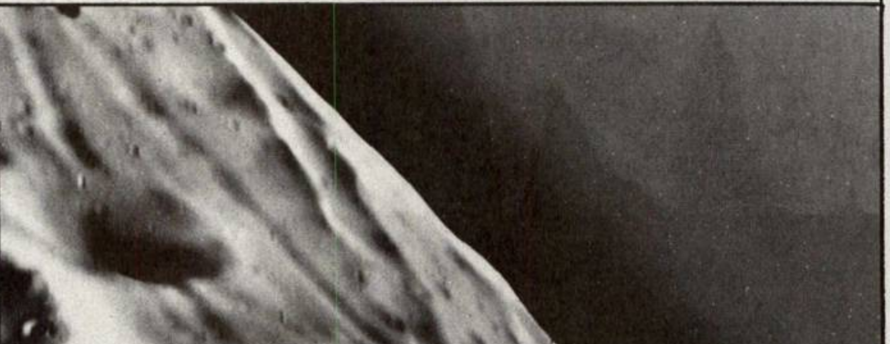
Another educational test use of the satellite links the University of South Pacific's main campus on Suva, Fiji Islands, to remote Pacific islands. Correspondence courses formerly conducted by mail are now done by satellite. Students on the remote islands can use the satellite to talk to professors at the main campus.

The VHF communications system onboard ATS-1 made history soon after the spacecraft was in synchronous orbit. It provided the first satellite link with inflight aircraft between pilots and air traffic controllers.

During a major flood in Alaska in August 1967, ATS-1 was the link between the disaster site and U.S. government agencies in the contiguous states.

Use of ATS-1 is planned for similar purposes in upcoming, follow-on tests with the ATS-6 satellite.

Close Up on Phobos



Viking Orbiter 1 took this close-up picture of the Martian satellite Phobos from a range of 75 miles (120 kilometers) – the closest range at which any spacecraft has photographed the tiny satellite. At that range, Phobos is too large to be captured in a single frame. This picture, taken on Feb. 20, 1977, covers an area 1.86 by 2.17 miles; a single picture element is about 39 inches (1 meter) across. However, the high relative speed of Orbiter 1 and Phobos caused some image smear so that the smallest surface feature identifiable is between 32 and 49 feet (10 and 15 meters) across. The picture shows a region in the northern hemisphere of Phobos that has striations and is heavily cratered. The striations, which appear to be grooves rather than crater chains, are about 328 feet to 656 feet (100 to 200 meters) wide and considerably longer. Craters range in size from 32 feet to 3/4 mile (1.2 kilometers) in diameter. The surface of Phobos appears similar to the highland region of the moon which also was heavily cratered and ancient terrain. The dark region above the limb of Phobos is an artifact of processing and does not indicate an atmosphere. NASA photograph.

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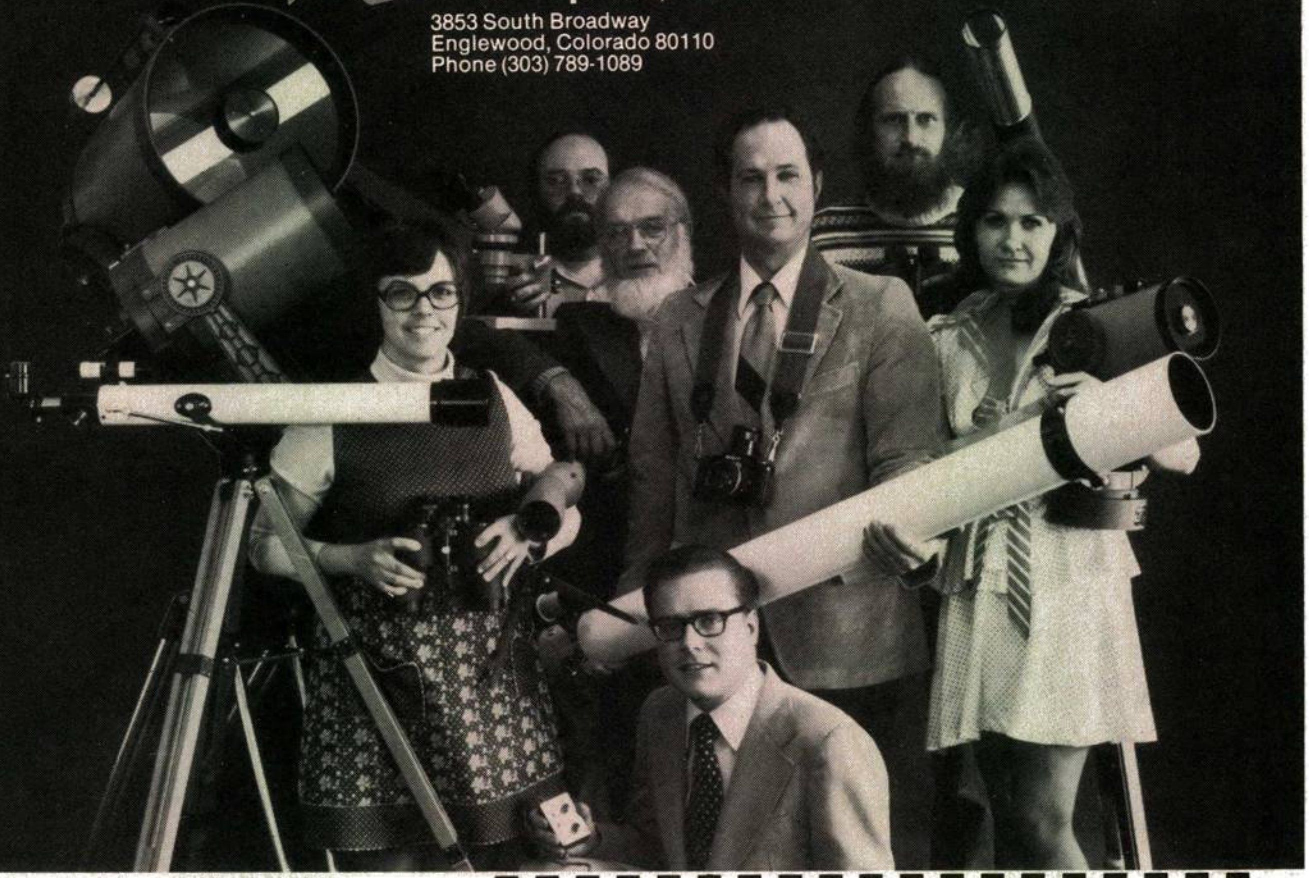

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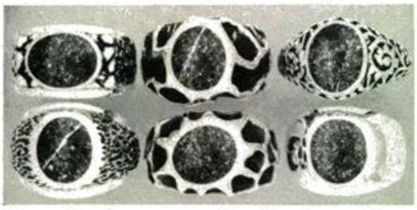

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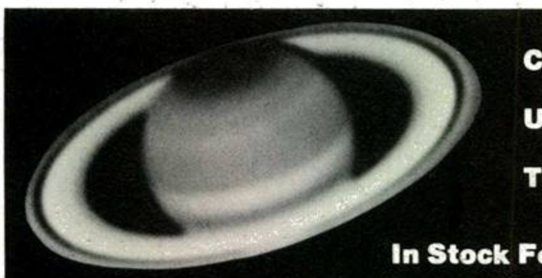

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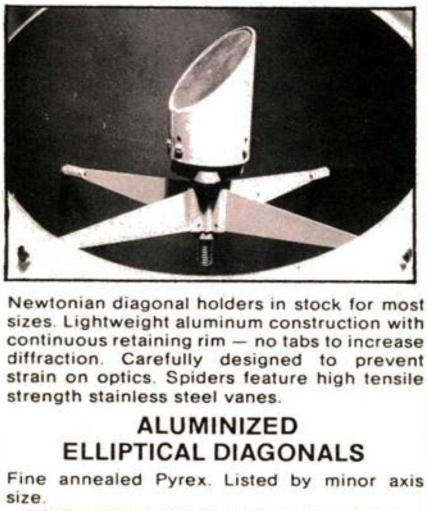

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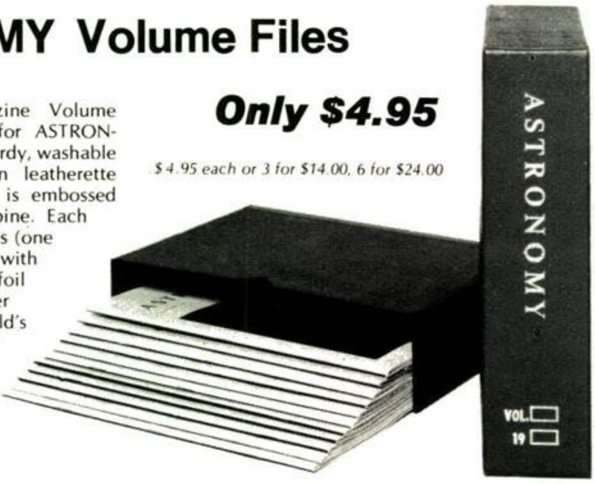

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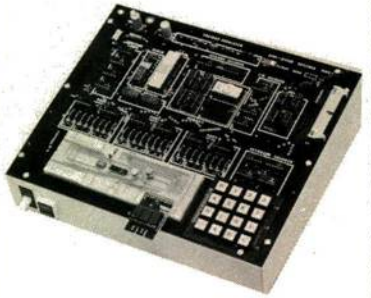

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WANTED — "Beyond Tomorrow: The Next Fifty Years in Space" by Dandridge Cole; published in 1965 by Amherst Press. Must be in excellent condition. Will pay $10.00. Write David P. Spiek, 556 E. Loula, Olathe, KS 66061.

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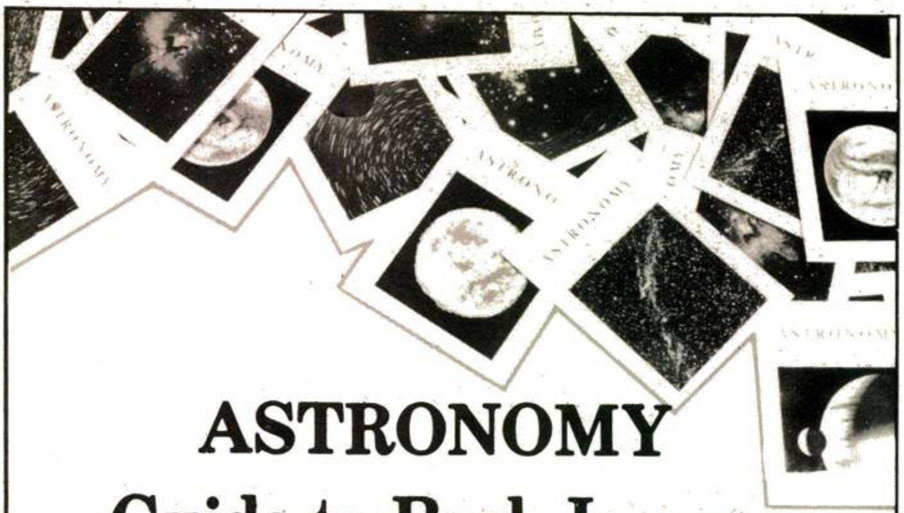

ASTRONOMY

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Reader interest in back issues of ASTRONOMY magazine is higher than ever. As a result, our stock of back issues is swiftly dwindling. Below is a guide to ASTRONOMY back issues that are still available. For your convenience it is updated monthly; issues not listed are depleted. **The July 1976 History of American Astronomy issue is specially priced at $3.50 per copy plus postage.**

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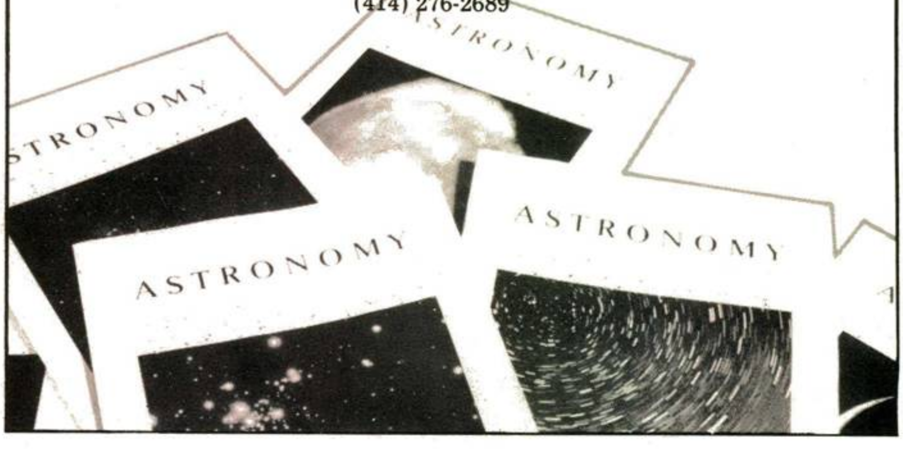

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Astronomy Summer 1977

STAR DOME

MAY

by

James Mullaney and Henry J. Phillips

Circumpolar constellations are the forgotten children of the night sky. Precisely because they're always available for observation as they circle the north pole, they tend to be neglected in favor of those star groups whose appearance on the sky's stage is limited to a mere two or three months. "I'll take a look at them tomorrow night," we mutter, as we turn our eyes and telescopes to the south. "After all, they'll still be there." True, but how many of us ever get around to "tomorrow night" and spend a few hours with the stars of the north?

Depending on where you live, the exact stars that are circumpolar will vary. If you observe from Alaska, for example, you're closer to Earth's north pole than someone in southern Florida, and a correspondingly larger section of the sky will circle the celestial pole without setting. If you want to find out exactly how much of the sky is circumpolar from your latitude, there's a simple way of finding out: Subtract your latitude in degrees from 90; the remainder will be the declination north of which stars are circumpolar from your observing site. For example, if you live at 30 degrees north latitude, stars with declinations of + 60 degrees or higher will be circumpolar. Also, the corresponding section of the sky around the south celestial pole will be invisible.

Six northern constellations are generally lumped together under the heading "circumpolar": Ursa Major, Ursa Minor, Draco, Cepheus, Cassiopeia and Camelopardalis. These groups never set from latitudes of about 40 degrees or higher.

From antiquity, the stars of Draco have represented a dragon, or a large serpent. Its twisting, coiling shape may have suggested this identification to its namers; or, because Draco formerly contained both the north celestial pole and the pole of the ecliptic, its serpentine character may have had great symbolic significance. (Snakes had always been thought of as mysterious and powerful.)

Dragons can be found in the mythology of many different races. Although details change from one nation to another, dragons' general outlines are similar. Their heads are vaguely reptilian, but their feet are usually the paws of predatory mammals, not reptiles. Dangerous and hostile to man, dragons are usually found as the protectors or guardians of some valuable treasure — be it gold, sacred objects, or a maiden in a tower. Sometimes, as part of their battery of offensive weapons, dragons breathe fire.

Greek mythology contains several of these guardian dragons. We noticed one in passing in March's Star Dome; a dragon kept watch over the golden fleece, which hung from a tree deep in the Colchian forest. Medea lulled it to sleep with one of her magic charms, allowing Jason to kill the beast, grab the fleece, and run.

Another dragon was conquered by Cadmus, the founder of Thebes. In preparation for a sacrifice, he sent servants to fetch water from the Spring of Ares, but the dragon that guarded this well devoured them. Where several of his servants failed, though, Cadmus alone succeeded; he attacked the monster and killed it single-handedly. The dragon's teeth subsequently proved potent weapons.

Yet another dragon was killed by Heracles during one of that hero's 12 labors; the dragon guarded the tree that bore the golden apples of the Hesperides. Heracles dispatched the dragon easily and was able to reach the apples.

The fiercest of dragons in Norse mythology, Fafnir, figures prominently in a story that deserves to be recounted in full.

The gods Odin, Hoenir and Loki were journeying through the world (Midgard) one day when they saw an animal frolicking in a nearby stream. In one of those acts of senseless violence (of which mythology is full), the gods killed the animal and skinned it for its pelt. Later, they stopped at a hut for the night; when the old man who owned it spied the pelt, he began alternately wailing and cursing. It came out that the gods had killed his son Otter, who habitually took the form of that animal. Otter's father demanded recompense in gold — enough to completely cover the pelt. Odin and Hoenir stayed behind as hostages while Loki left to fetch the gold.

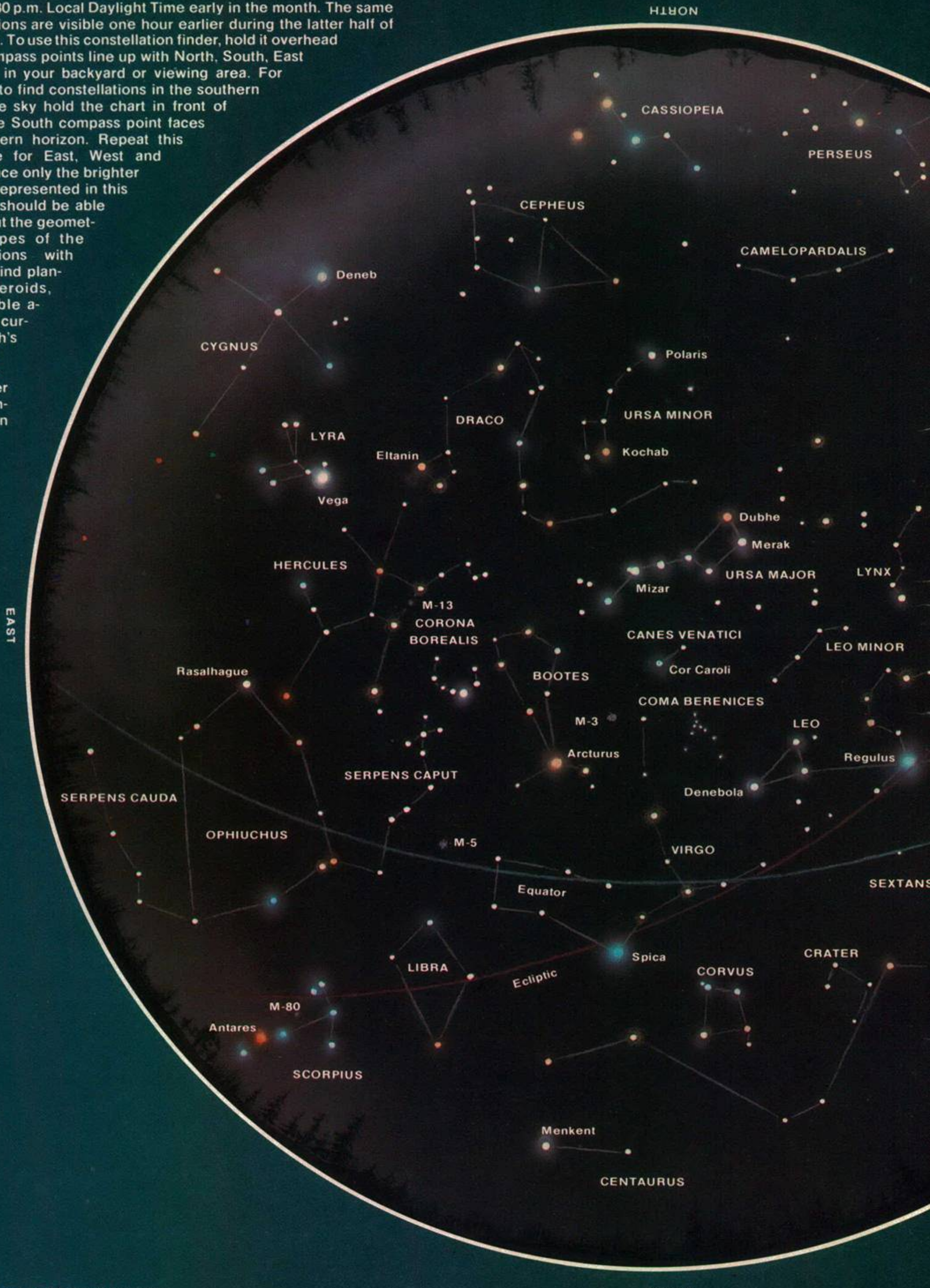
Loki, a notorious trickster, captured a dwarf named Andvari, and freed him only in return for the dwarf's hoard of gold. Andvari tried to conceal a magic ring, but Loki forced it from his hand. Andvari cursed the ring for all time, proclaiming death for everyone who owned it. When Loki returned to the hut (keeping the ring for himself), the hoard entirely covered the pelt but for the tip of a whisker. Otter's father noticed the ring on Loki's hand and demanded it, and Odin prevailed upon Loki to give it up.

Immediately the curse took effect. Otter's two brothers, Regin and Fafnir, were inflamed with desire for the hoard and killed their father to get it. Regin wanted only the ring as his share, but Fafnir refused to give it up; taking away the entire treasure, he stowed it in a cave and changed himself into a huge dragon to guard it.

Regin, smoldering with hatred, vowed to obtain the ring. He talked his way into the court of King Alf of Norway as the tutor of Alf's stepson Sigurd. When the boy was old enough and showed his great strength, Regin hinted that the killing of Fafnir would be a bold deed that would bring the boy renown. Sigurd, proud and boastful, was stung by Regin's taunts of cowardice, and one day the two rode off to Fafnir's cave.

Regin hid as Sigurd killed Fafnir; the dying dragon informed Sigurd that he knew who had set him on to

This Star Dome rendering approximates the sky as it appears at about 11:30 p.m. Local Daylight Time early in the month. The same constellations are visible one hour earlier during the latter half of the month. To use this constellation finder, hold it overhead so the compass points line up with North, South, East and West in your backyard or viewing area. For example, to find constellations in the southern part of the sky hold the chart in front of you so the South compass point faces the southern horizon. Repeat this procedure for East, West and North. Since only the brighter stars are represented in this map, you should be able to trace out the geometrical shapes of the constellations with ease. To find planets, asteroids, etc., visible among the current month's zodiacal constellations, refer to the planet finder on page **36**


NORTH
CASSIOPEIA
PERSEUS
CEPHEUS
CAMELOPARDALIS
Deneb
CYGNUS
Polaris
URSA MINOR
DRACO
LYRA
Kochab
Eltanin
Vega
Dubhe
Merak
HERCULES
URSA MAJOR
LYNX
Mizar
M-13
CORONA
BOREALIS
EAST
CANES VENATICI
LEO MINOR
Rasalhague
Cor Caroli
BOOTES
COMA BERENICES
M-3
LEO
Arcturus
Regulus
SERPENS CAPUT
SERPENS CAUDA
Denebola
OPHIUCHUS
M-5
VIRGO
SEXTANS
Equator
LIBRA
Spica
CRATER
CORVUS
Ecliptic
M-80
Antares
SCORPIUS
Menkent
CENTAURUS
SOUTH

Map Centered on 40° North Latitude

Capella
AURIGA
GEMINI
Castor
Pollux
CANIS MINOR
M-44
CANCER
Procyon
MONOCEROS
HYDRA
Alphard
WEST

Map by Adolf Schaller

the deed, and that it gladdened him that Regin was working for Sigurd's death also. Regin, returning, asked Sigurd to roast the dragon's heart for him. A drop of blood from the heart burned Sigurd's finger, and when he put it to his mouth, the blood on his tongue enabled Sigurd to understand the language of the birds. From their chatter, Sigurd learned for the first time of Fafnir's hoard and Regin's treachery; he drew his sword and struck off Regin's head.

But the curse continued to work; when Sigurd obtained the hoard, he also found and wore the ring. It destroyed Sigurd and all those who came in contact with him, and the curse ended only when the ring was lost in the sea.

Other dragons can be found in the lore of other nations. The Chinese dragons are well known, figuring prominently in much Chinese art; they are much more benevolent than their Western counterparts. The four Dragon-Kings of Chinese legend ruled the four seas; each lived in a crystal palace, with an army composed of fish, crabs and lobsters. The Dragon-Kings were called upon during droughts because they brought rain. Processions through the streets of a town often included the cloth effigy of a dragon.

Any or all these dragons can spring to the mind of the observer who watches Draco make his endless round of the north pole. As he bends around Ursa Minor, separating the little bear from his southern neighboring constellations, perhaps we can still consider the dragon as guardian — of the glowing jewel Polaris, the star that marks the pole.

Close-Up

Draco Region

Mighty Draco is a constellation to be reckoned with, for the dragon winds nearly 180 degrees about the north celestial pole and covers more than 1,000 square degrees of the sky! Ranking eighth in order of size among the constellations, it is nonetheless rather dull looking over much of its length and even difficult to identify in places. Its brightest star is 2.21 magnitude Gamma (γ), whose proper name is Eltanin. The lovely tint of this orange K-type sun caused Barns to describe it as "a gem".

Draco is circumpolar (always above the horizon) for observers above 40 degrees north latitude. Its most interesting area is that around the dragon's head — just above Hercules and now becoming well placed for exploration in the northeastern sky.

Olcott pointed out that the four stars in the head, together with nearby Vega, offer a convenient magnitude sequence for naked eye observers. With the addition of Deneb in Cygnus, we can actually cover the six magnitude interval from zero to five. The sequence stars and their magnitudes run as follows: Vega, zero; Deneb, one; Gamma Draconis, two; Beta (β), three; Xi (ξ) or Nu (ν), four, and Mu (μ), five. Keep the sequence in mind on the next clear night; it may prove useful if you want to check the magnitudes of other nearby stars.

Both Olcott and Webb commented that Draco is rich in double stars. Indeed, this month's region might well be called "the land of double and multiple suns", as our table of selected objects shows. This list includes only a few of the more attractive twins and triplets among the hundreds located in this part of the sky.

Here, as elsewhere in the heavens, double stars outnumber other types of deep sky objects in the classic observing lists by a factor of better than ten to one! With the exception of the spiral galaxy NGC-6503 and the planetary nebula NGC-6543, there are no prominent nebulae or galaxies in this extensive region, and an almost total lack of open clusters.

NGC-6543 itself is a vivid blue-green planetary located at the first "bend" in the dragon's body, very near the north pole of the ecliptic. It was described in detail (together with a color drawing) in the April 1976 Star Dome. The nebula is well worth observing while surveying the wonders of Draco.

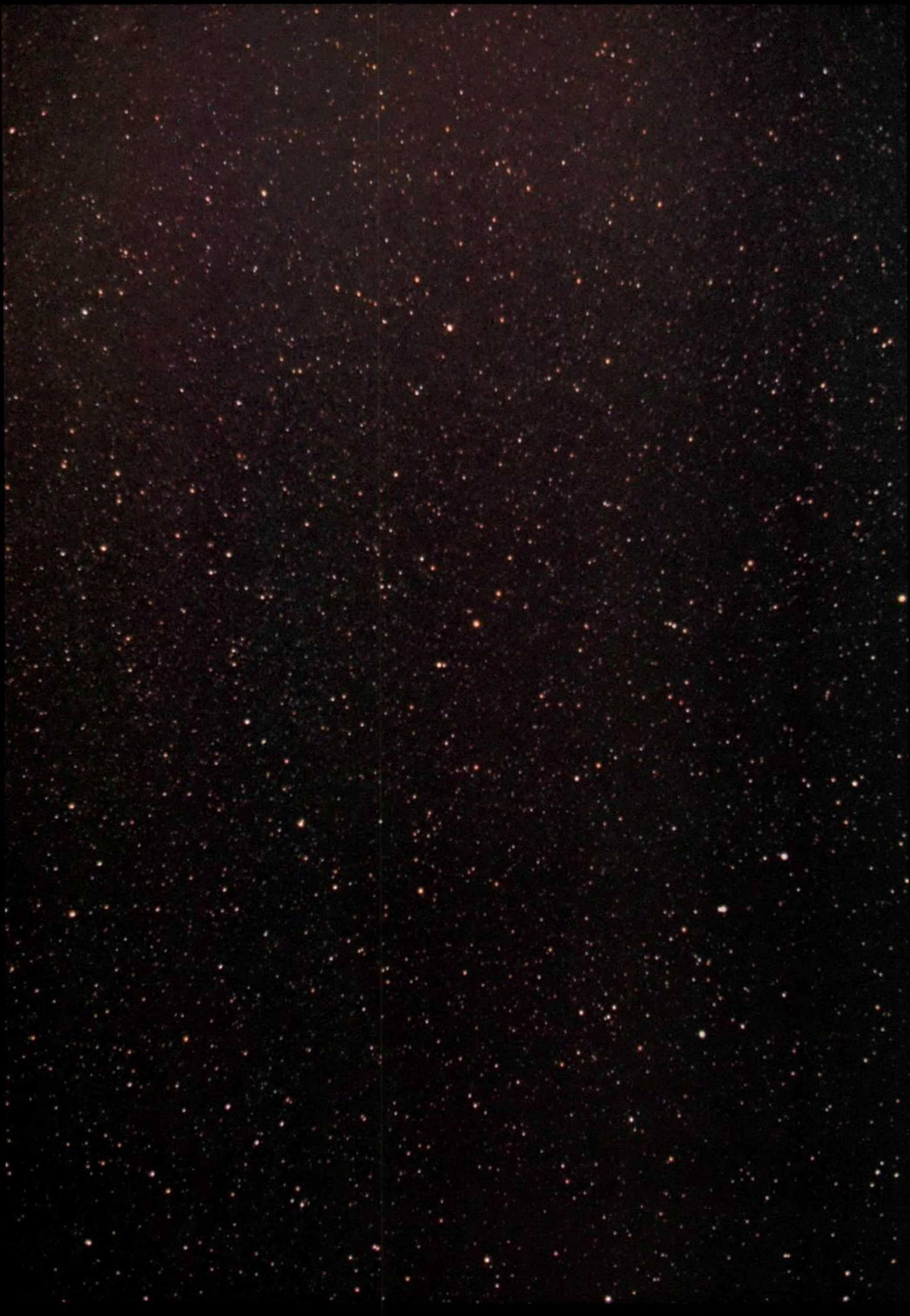
RY and UX Draconis

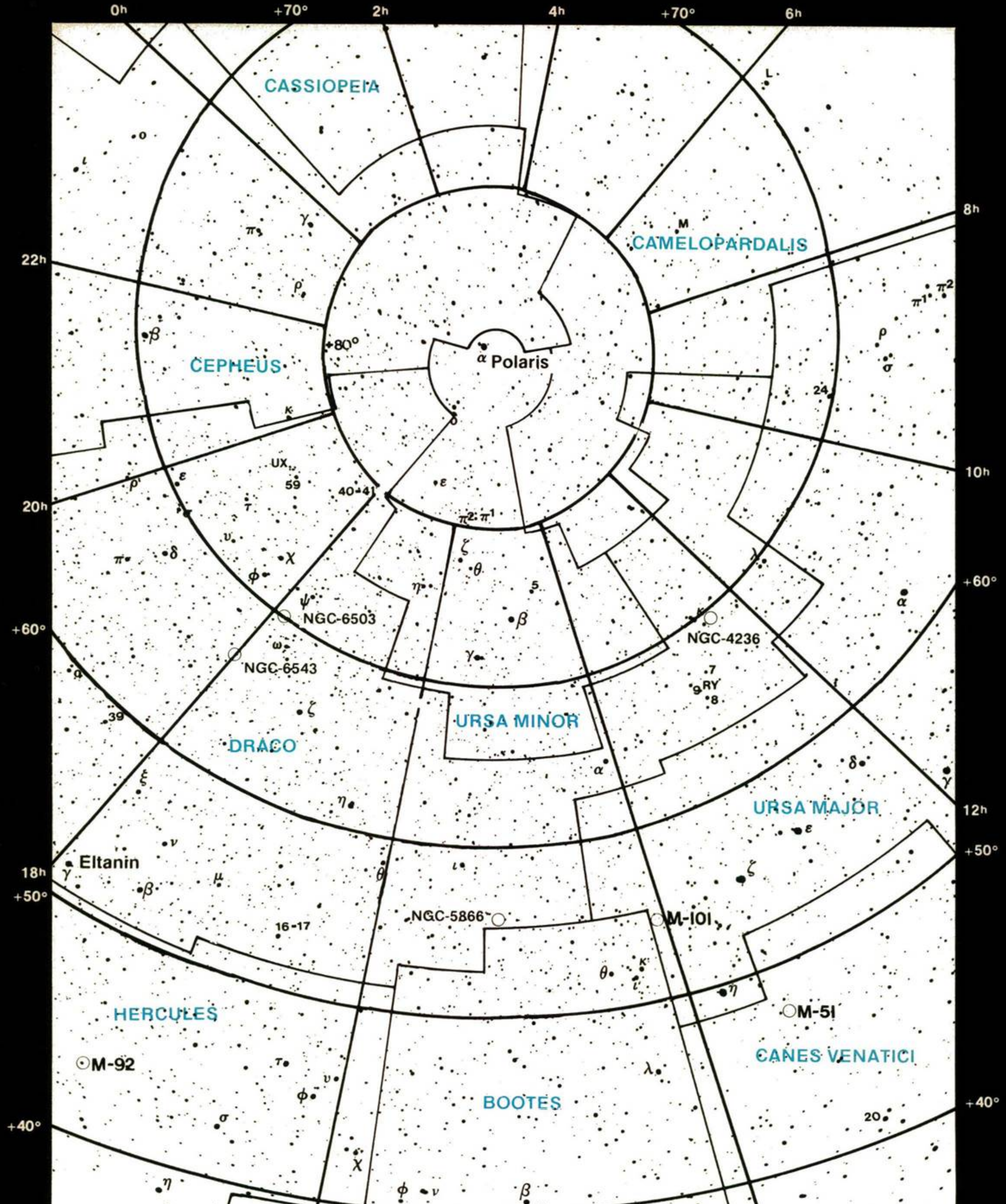
We begin by sampling the "unattached" single stellar population of Draco. Gamma's fine warm hue has already been mentioned, but it cannot rival the deep red tints of two variable stars found in this region. These are RY and UX Draconis, located on opposite sides of the constellation. Both are semiregular pulsating suns of spectral class N.

The brighter of the two at maximum light is RY Draconis, situated about 1/3 of the way along a line from Epsilon (ε) Ursae Majoris (in the Big Dipper's handle) to Polaris. A finder will show it nestled within a distinctive little triangle of fifth magnitude stars (7, 8 and 9 Draconis). This restless sun varies from magnitude 5.6 to 8.0 over a period of 172 days.

UX Draconis exhibits a much smaller range of variation — this time from 6.2 to 6.9 magnitude, with a period of 168 days. You can find it by sweeping the sky very near the star 59 Draconis, a little less than halfway along a line from Delta (δ) Draconis to Polaris.

Both stars are included in many of the classic lists but always without

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2h
4h
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6h
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22h
10h
20h
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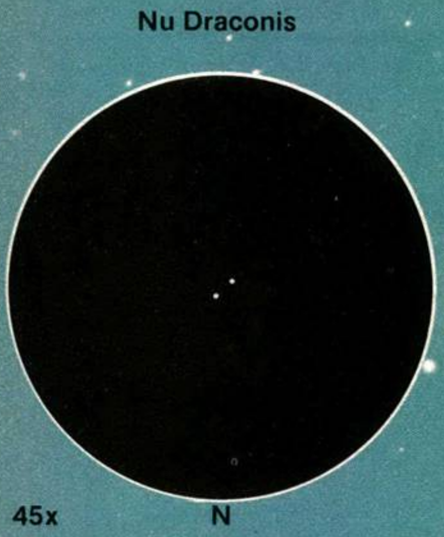
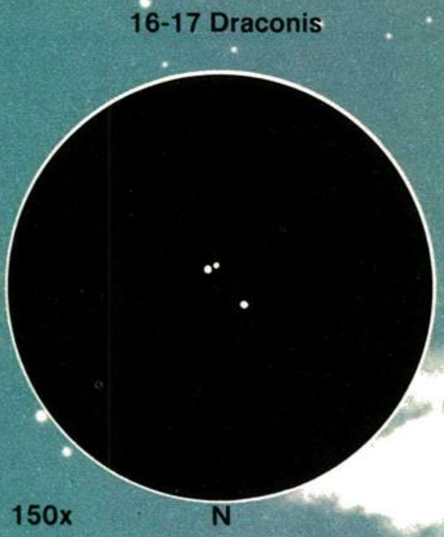
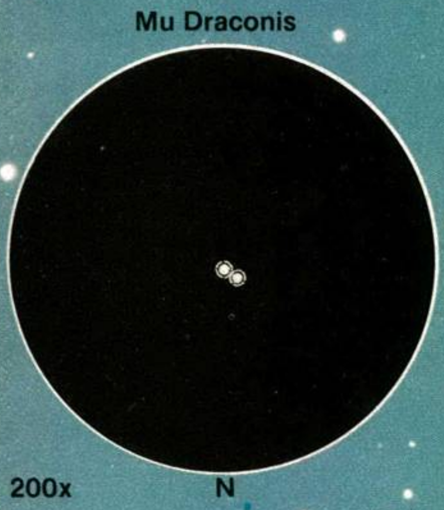
+50°
+40°
+40°
16h
14h
CASSIOPEIA
CAMELOPARDALIS
CEPHEUS
+80°
Polaris
URSA MINOR
DRACO
URSA MAJOR
Eltanin
NGC-6503
NGC-6543
NGC-4236
NGC-5866
M-101
M-51
M-92
M-13
HERCULES
BOOTES
CANES VENATICI
CORONA BOREALIS
UX
59
40-41
24
16-17
9 RY
7
8
39
20
5
L
M

Photography by Brad Wallis and Robert Provin/Map by Henry J. Phillips

description or comment. Why this is so is something of a mystery, for either star is a stunning sight on dark transparent nights. Especially when atmospheric turbulence is high, these flickering crimson suns look like interstellar beacons amid the celestial traffic of the north polar region!







Upper left: Nu Draconis may be the finest binary among the many to be found within the borders of Draco. The exactly matched pair, seen by most observers as white, is viewed here through a three inch refractor at 45 power; the field of view is about one degree. Lower left: Like Nu, Mu Draconis is a binary of equally bright white components, but with a much narrower separation. A five inch Schmidt-Cassegrain at 200 power was used for this drawing, which has a field of view of 10 minutes of arc. Above: 16-17 Draconis is a triple system; the brighter components are visible as a binary in binoculars. The colors in this system are extremely subtle. This drawing shows the triple as seen through a four inch reflector at 150 power, with a field of view of about 1/3 second of arc. Drawings by James Mullaney.

Selected Objects — Draco Region

Object	Type	Mag.	Size/ Sep.	R.A. (1950)	Dec.
NGC-4236	SB	10.1	20' x 5'	12^h14^m	+69°45'
* RY Draconis	V:172^d	5.6-8.0	—	12^h55^m	+66°16'
NGC-5866	El	10.8	2.8'x1'	15^h05^m	+55°57'
* 16-17 Draconis	★3	5.6,5.6,6.6	91", 4"	16^h35^m	+53°01'
* μ (Mu)	★2	5.8, 5.8	2"	17^h04^m	+54°32'
* ν (Nu)	★2	5.0, 5.0	62"	17^h31^m	+55°13'
* ψ (Psi)	★2	4.9, 6.1	30"	17^h43^m	+72°11'
NGC-6503	Sp	9.6	4' x 1'	17^h50^m	+70°10'
+ NGC-6543	PN	8.8	22"	17^h59^m	+66°38'
40-41 Draconis	★2	5.8, 6.2	19"	18^h04^m	+80°00'
* 39 Draconis	★3	4.9,7.7,7.1	4", 89"	18^h23^m	+58°46'
* ο (Omicron)	★2	4.8, 8.2	34"	18^h51^m	+59°20'
* UX Draconis	V:168^d	6.2-6.9	—	19^h23^m	+76°28'
ϵ (Epsilon)	★2	4.0, 7.1	3"	19^h48^m	+70°08'

* Detailed in Close-Up
+Detailed in Star Dome, April 1976

★2 = Double Star
★3 = Triple Star
PN = Planetary Nebula
El = Elliptical Galaxy
Sp = Spiral Galaxy
SB = Barred Spiral Galaxy
V:#d = Variable Star, period (days)
Mag. = Magnitude
Sep. = Separation

Nu (ν) Draconis

Perhaps the finest double star among the multitude in this month's region lies in the dragon's head, just above Beta. This is Nu Draconis, an exactly matched pair of fifth magnitude white stars 62 seconds of arc apart — wide enough to make them visible even in finders and binoculars.

Smyth described the stars as "pale gray", and most observers see them as colorless. Off-white tints have been reported; however, Webb saw this duo as yellowish white and considered Nu "a grand object". Others have gone so far as to call both stars yellow.

This superb object is one of the very few wide pairs that remains attractive in large telescopes with their greater image spread. Barns, for example, called Nu "exceptionally fine" in his 10 inch reflector, and they are still a showpiece in a 13 inch refractor.

Nu Draconis is at its best, however, in small telescopes at very low magnifications. A two inch refractor at just 30 power gives a thrilling view! The pair exerts a fascination to observers that is difficult to explain when we consider its lack of color and wide separation. Perhaps it has something to do with seeing two so perfectly matched suns glowing against an empty black sky — a sight somewhat like that shown in our drawing.

Both components of Nu are drifting through space together, forming a common proper motion (CPM) pair; the possibility exists that they are actually a very long period, slow moving binary. This duo is sure to please visitors at the telescope, as well as old hands who have never dared to venture close enough to the fearsome dragon to have seen it yet!

Psi (ψ) Draconis

If Nu's anemic appearance leaves you longing for some color in your next object, try the pretty double star Psi Draconis. It is located north of the dragon's head, about midway to Polaris (our trusty anchor star for this region). Gamma and Xi in the head point northward, directly at it.

This pair consists of 4.9 and 6.1 magnitude stars, 30 seconds of arc apart. Some early descriptions, and at least one modern one, describe the components as white or pearly white. But as Webb pointed out, a color contrast is evident. Virtually all observers agree in calling the primary yellow and the companion lilac. At least one forgotten list dating from the 1890s (the **Celestial Handbook** by Colas) includes Psi under its heading of finest colored double stars.

In a sense, we are removing some of the fun and challenge from double star observing by telling you what colors to expect before you have seen the objects. This could easily bias your perception of these often delicate celestial tints. Try recording your impressions of the pairs listed in our table each month *before* reading their descriptions. The results may prove quite fascinating!

In judging star colors, use well-corrected eyepieces such as orthoscopics and place the object under study at the center of the field of view to avoid spurious results. Direct rather than averted vision will often prove best for such work because of the eye's properties. Yet another hint is to slightly defocus the image to spread the star's light over a greater area of the retina. This is something that poor "seeing" (image steadiness) often does for you anyway. Try going both inside and outside of focus, and compare the tints you see.

Recording double star colors is a fascinating activity but one that unfortunately receives little attention from modern stargazers. "Show" pairs like Albireo are easy, but pinning down specific tints for objects like Psi Draconis takes skill. In time, your eye will become finely tuned for such studies — revealing beauty among the stars never before suspected.

Omicron (*o*) Draconis

Another Draconian double star offers contrast both in color and brightness. This is Omicron, located about 15 degrees east and north of the head area. A line from Nu through Xi points roughly to its position.

Here we find a 4.8 magnitude primary and a delicate 8.2 magnitude companion sun an easy 34 seconds of arc apart. While this pair can be glimpsed even in a 2.4 inch refractor, the relative dullness of the small star makes the tints definite only with larger apertures. Six inches or more are really needed to appreciate Omicron's charm.

Among the colors reported for this object are orange and green or emerald, and yellowish orange and lilac. Deep yellow and blue or "ashy" have also been seen. Here we're faced with the other side of the coin in our presentation of double star colors: Knowing what to look for before going to the eyepiece is an excellent way of "educating" the eye-brain sensory unit. Low key duos like Omicron Draconis are ideal for such schooling.

Mu (μ) Draconis

The variety among double stars is simply endless! As an example, we turn our attention from wide pairs to a close binary system whose movement can be followed over the years even in small telescopes. This is Mu Draconis, situated midway between the two binocular duos Nu and 16-17.

Like Nu itself, both components of Mu are white and nearly a perfect match in brightness. The separation of the stars in the former, however, is more than 30 times that in the latter! The actual figures for Mu show that both stars shine at magnitude 5.8 and are presently a very close two seconds of arc apart. The two suns are also of the same spectral class (F6).

Mu Draconis was at one time thought to be a very long period binary, whose circuit required as much as 2,000 years to complete. More recent results, however, have shown its period to be much shorter — about 480 years. Closest approach of the two suns is predicted for 1988, when their separation will be about 1.9 seconds. This is very nearly its present value, so you'll see little change in this parameter over the coming decades. Maximum separation of 4.5 seconds is expected in the year 2180.

Although Mu's separation is now relatively constant, its position angle will continue to change noticeably over the years. Currently it is decreasing — meaning that the components are moving clockwise with respect to each other. Back in 1830, its position angle was measured at 200 degrees; in 1955, it was near 80 degrees; in 1975, 50 degrees, and in 1995, it will have diminished to 15 degrees (nearly due north in the sky).

A three inch refractor at high magnification will resolve this pair in good seeing and a four inch glass will cleanly split it. Such instruments — together with lots of time and patience — are all that's needed to witness the spectacle of two suns moving about each other in the depths of interstellar space!

At least one source considers Mu Draconis "a pretty pair" — and so it is with sufficient resolution, as shown in our drawing. Most small instruments will show the two stars apparently in contact with each other on steady nights, and as a blended blob of light on other occasions.

Mu is actually a triple system, for a 13th magnitude star 14 seconds distant has been found drifting through space with it. There are also puzzling astrometric perturbations in the bright pair's orbit that may signal the presence of an unseen companion. This complex and fascinating system lies about 76 light-years from us.

39 Draconis

For a change of pace, we now examine two fine triple stars from among the many to be found in Draco. The first of these is 39 Draconis, located about midway between Xi and Omicron.

This object consists of three suns of magnitudes 4.9, 7.7 and 7.1. The companions' distances from the primary are 4 and 89 seconds, respectively. Some observers perceive 39 as an unequal double with a third star nearby. Can you confirm this impression in your telescope?

Barns described this "double plus", or triple, as "wide — impressive — colorful", evidently referring to the two brightest members. Webb gave the tints here as white, ruddy and lilac. Yellowish white, bluish and ash have also been reported.

16-17 Draconis

We conclude our survey of this month's region with another triple system. While Nu ranks as Draco's finest double, 16-17 Draconis is its best triple. It can be found west of the dragon's head by following a line from Gamma through Beta twice their separation. Binoculars and finders will show an apparent double star, which scrutiny with a small telescope transforms into three objects.

We again encounter a nearly matched pair of stars, for both 16 and 17 Draconis shine at magnitude 5.6. The distance between them is just over 90 seconds of arc. A 6.6 magnitude companion attends 17 at a separation of four seconds, forming a striking triple system. The wide pair is moving through space together; the close one is of uncertain type, but is probably a binary.

A 2.4 inch refractor at about 100 power resolves all three stars nicely in good seeing, while four inch and larger instruments give the kind of view shown in our drawing. As aperture increases, this object becomes even more lovely.

As with 39 Draconis, a number of observers (both past and present) have viewed 16-17 as double rather than triple! Barns, for example, listed 17 and its companion without any mention of nearby 16. It's fun trying to unravel the basis of such unusual observations by the great observers of the past. Going to the eyepiece ourselves is often the only answer.

Smyth gave the colors of 16, 17A and 17B Draconis as white, pale yellow and faint lilac, respectively. Webb agreed closely with white, white and pale lilac. Cream and bluish have also been given for the 17 pair, while many observers today see all three stars a pale greenish-white in hue. Get your vote in for this stunning triplet the next clear night!

All the objects we have surveyed this month in Draco are visible to the unaided eye, but finding them requires attentive constellation identification. This holds true for locating most of the beautiful deep sky wonders scattered in such profusion about the sky, giving added meaning to the well-known plaint of Carlyle: "Why *did* no one teach me the constellations when I was a child?"

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